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Special IYPT2019 ►

Elements of X ►



Elements of IYPT2019

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Cover: The chemical elements tiles illustrating the features of this special IYPT2019 issue of *Chemistry International* are part of the IYPT Timeline of Elements project organized by Chem 13 News and the University of Waterloo in Ontario, Canada. See Elements of Credits page 3.

The Periodic Table of Chemical Elements has without any doubt developed to one of the most significant achievements in natural sciences. The Table (or System, as called in some languages) is capturing the essence, not only of chemistry, but also of other science areas, like physics, geology, astronomy and biology. The Periodic Table is to be seen as a very special and unique tool, which allows chemists and other scientists to predict the appearance and properties of matter on earth and even in other parts of our the universe.

March 1, 1869 is considered as the date of the discovery of the Periodic Law. That day Dmitry Mendeleev completed his work on *"The experience of a system of elements based on their atomic weight and chemical similarity."* This event was preceded by a huge body of work by a number of outstanding chemists across the world. We have elaborated on that in the January 2019 issue of *Chemistry International* (<https://bit.ly/2IHKzS5>). The greatness of Mendeleev was that not only did he leave spaces for elements that were not yet discovered, but he also predicted properties of five of these missing elements and their compounds. Within Mendeleev's lifetime, three of these missing elements were discovered by others. Years after Mendeleev's discovery, the inert gases were discovered and could be placed in the Table.

During the year 2019, we are celebrating worldwide the Periodic Table as Mendeleev proposed it in 1869 and the Table's on-going developments. The Table can be depicted in a variety of formats, and today a database of (almost) all Periodic Tables, used in the last 150 years, worldwide, is available and maintained by Mark Leach: https://www.meta-synthesis.com/webbook/35_pt/pt_database.php

The year has been full of activities worldwide. Too many to mention, and those reported are listed on the website **www.iypt2019.org**. On January 29, the flagship Opening Ceremony was celebrated with over 700 delegates from over 50 countries in Paris on the UNESCO premises. Now, we are looking forward to the Grand Closing Ceremony, in Tokyo, Japan on December 5. Our Japanese colleagues are preparing an exciting program, promising for a high-level closure of our IYPT2019; see <https://iypt.jp/en.html>

The International Year of the Periodic Table of Chemical Elements has no doubt enhanced international cooperation by coordinating activities between learned societies, educational establishments, and industry. By focusing specifically on new partnerships and initiatives in the developing world and by establishing durable partnerships to ensure that these activities, goals and achievements continue in the future beyond the year 2019, a major step had been made. The success of the activities has become very clear already during the Opening Ceremony and the large number of international events that took place throughout 2019.

This special issue of *Chemistry International* is meant to show several aspects of chemical elements, celebrating once more IYPT2019. I do wish that the readers will enjoy reading this excellent issue as much as I did.

Jan Reedijk <reedijk@chem.leidenuniv.nl> is co-chair with Natalia Tarasova of the InterUnion Management Committee for IYPT 2109. (See IYPT2019 Introduction, CI Jan 2019, p. 2 <https://doi.org/10.1515/ci-2019-0101>)

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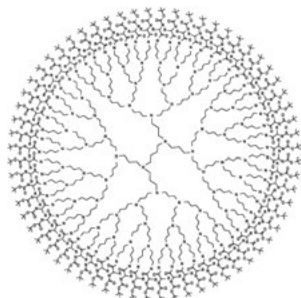
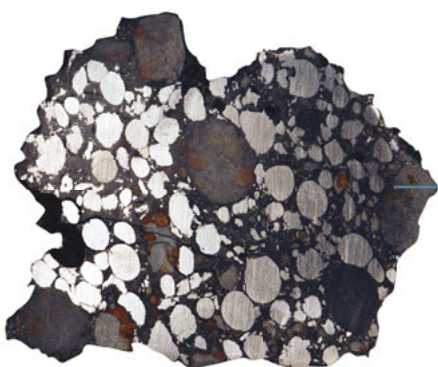
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Elements of X

by Lars Öhrström, Special issue editor

We are moving into the last part of the 2019 International Year of the Periodic Table and one wonders: Is there anything left to say? Has the equation *Elements of X*, not been thoroughly investigated? Not quite we think, and an amazing set of authors from around the globe* who accepted the challenge adequately proves the point in this special issue of *Chemistry international*.

Not only do we cover some diverse geographical terrain, this collection also emphasizes that the IYPT2019 did not come to be because of IUPAC only; physics, astronomy, biology, philosophy: they all come together in the Periodic Table. So we want to acknowledge our fellow international unions: International Union of Pure and Applied Physics (IUPAP), European Association for Chemical and Molecular Science (EuCheMS), the International Science Council (ISC, previously ICSU), International Astronomical Union (IAU), and the International Union of History and Philosophy of Science and Technology (IUHPS).

We start with a discipline that truly unites us all, teaching. A lot has been written about Dmitry Mendeleev and his 1869 table, but one thing academic researchers all over the world will do well to remember, when we complain of heavy class room duties, is that this major breakthrough in Science came because Mendeleev needed it to improve teaching of his students. And who better to tell us about this in the *Elements of Education*, than **Peter Atkins**, perhaps the best known now living chemistry textbook writer. He discusses inorganic chemistry, physical chemistry, organic chemistry, but also chemistry for the general public and the value of a chemistry education in commerce and trade. Plus a bit of philosophy, otherwise it would not be Peter Atkins.

The general things that Peter pushes for are abundantly present in **María Lugaro & Ewine van Dishoeck's** essay on the *Elements of Stars*. What other subject touches our imagination and give us this sense of wonder other than astronomy? We are all made of star stuff as Marie and Ewine show us, and with that we also get a bit of science history.

And science history, perhaps unexpectedly given the title, we get plenty of in **Kit Chapman's** *Elements of the Future*. Peter just arrives at the latest elements in his essay, and Marie and Ewine lay a great foundations by telling us about nuclear reactions in stars, and how elements not existing on Earth can be found in Space. Kit, however, will make us meet some real scientific

superstars, both living and dead. And the element hunt certainly takes us to some unexpected places, like the San Francisco Bay area subway system, BART, and stained-glass windows of Russian churches.

A fair distance south of San Francisco and Berkeley, where some of the action takes place in Kit's story, lies Pasadena and the California Institute of Technology. This institution's most famous contribution to the Periodic Table is perhaps Richard Feynman's suggestion that the elements end at $Z=137$, something Kit told us in the preceding essay.

A less known contribution to science is that one of its chemical engineering graduates brought serious chemistry, still relevant today, to Hollywood in the 1930s. In *You Can't Take It with You* from 1938 director Frank Capra has the leading actors, James Stewart and Jean Arthur, discuss the molecular origin of the photosynthesis. Stewart confesses that solving the mystery of this reaction is what he really wants to do with his life, not become a money-maker like the rest of his family. Such work is still indeed going on, and in *Elements of Life* we get a very personal treatise on (di)oxygen, some of the metallic elements of enzymes and their relevance to life and death, by the doyen of bioinorganic chemistry, Caltech professor emeritus **Harry Gray**.

With whatever element it takes, solving the problem of artificial photosynthesis surely has both commercial and societal value and in *Elements of Technology* **Michael Droescher** takes us through some of the elements that have been crucial to our technological advances. A Periodic Table of human History may start with the not so elemental elements of "stone" and "bronze" but Michael takes us all the way from them to the latest atom types relevant for our history such as lithium, cobalt and helium.

Obviously, commercial and societal value is related to abundance and ease of extraction and recycling. Michael touches on these subjects but in *Elements of Scarcity* **David Cole-Hamilton** really gets to the core of what it means for us to live on a planet with limited resources.

Some of these resources have always been scarce and therefore highly valued. Some of this value was, and is, because we can use these elements and compounds to enhance our social status, our desirability, or for the plain and simple joy of making ourselves and our appearances pretty, funny, or artistic. So, in *Elements of Flair and Fashion* **Marielle Agbahoungbata** will take us from the ancient Egyptians to the Lagos Fashion Week in Nigeria. In doing so she will pass through the animal, plant, and mineral kingdoms, but also touch upon some

1. An Asian contribution on the theme will appear in the next issue of CI

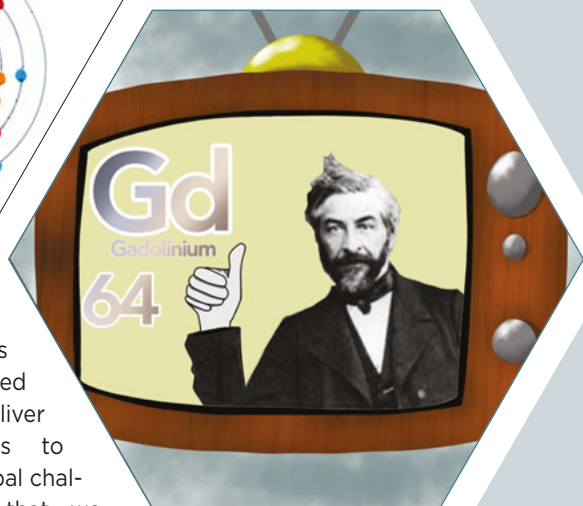
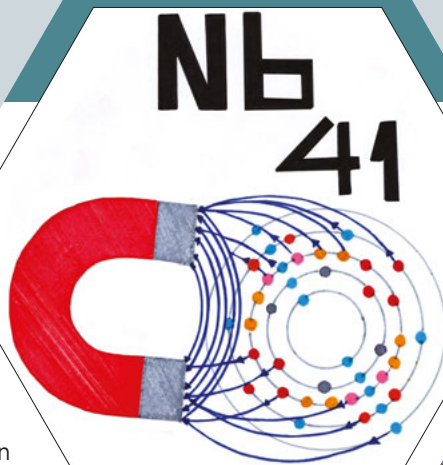
environmental issues that both large and small scale dyeing businesses encounter. Marielle herself has done research on the subject in her native Benin in West Africa.

Now, for anybody even just faintly knowledgeable about the world of super heroes, the geographical connection to the next and final story by **Suze Kundu** is obvious. The fictional element vibranium of course has its origins in the sub-Saharan African country Wakanda (likewise fictional) and form the basis of a number of technological inventions in the Marvel Comics universe. But in Suze's *Elements of Heroism* we will also venture into the worlds of Star Trek and Lord of the Rings.

Fictional as they may be, and perhaps even outrageous to a few because of some of their proposed properties, these elements and their fictitious applications in technology, may nevertheless be inspirational to both old and young minds alike. And now we have come full circle to Peter's first essay on *Elements of Education*: we need to teach and inspire about the elements and their compounds, and if we do that, then we will indeed have equipped new generations with the real

super-powers they need to deliver solutions to the global challenges that we face.

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Elements of Credits

The chemical elements tiles illustrating the features of this special IYPT2019 issue of *Chemistry International* are part of the IYPT Timeline of Elements project organized by *Chem 13 News* and the University of Waterloo in Ontario, Canada. The project attracted worldwide participants. Teachers were asked to apply on behalf of their students to design an artwork for one assigned element. 200 applications from over 29 countries were initially received, and ultimately all the elements were assigned to 118 schools from 28 countries, including every province and territory in Canada.

See more details and all artwork and final poster online: <https://uwaterloo.ca/chemistry/community-outreach/2019-international-year-periodic-table-timeline-elements>

The Timeline of Elements will also be turned into a full-wall mural (16 m x 3.3 m) and an interactive exhibit in the Science Teaching Complex (STC) of the University of Waterloo. The grand unveil and opening is scheduled for 26 October 2019.

CI editors would like to acknowledge the Timeline of Elements organizers for their willingness to share their project with CI readers. Special thanks to Jean Hein and Heather Neufeld, and to the following students/schools whose elements are reprinted in this issue (in order of appearance):

Nb, niobium, 41—Escuela Colombiana de Ingeniería Julio Garavito—Bogotá, D.C., Colombia—Teacher: Angela Mercedes Quiñones-Castañeda—Artist: Collaboration of students and teachers

Gd, gadolinium, 64—Ozel Sisli Terakki Tepeoren Anadolu Lisesi—Istanbul, Tuzla, Turkey—Teacher: Gulsen Sokullu—Artist: Alara Aydin

continued on page 38

Elements of Education

by Peter Atkins

The periodic table was born in chemical education and thrives there still. Mendeleev was inspired to create his primitive but pregnant table in order to provide a framework for the textbook of chemistry that he was planning, and it has remained at the heart of chemical education ever since. It could be argued that the education of a chemist would be almost impossible without the table; at least, chemistry would remain a disorganized heap of disconnected facts. Thanks to Mendeleev and his successors, by virtue of the periodic table, chemical education became a rational discussion of the properties and transformations of matter. I suspect that the educational role of the periodic table is its most important role, for few research chemists begin their day (I suspect) by gazing at the table and hoping for inspiration, but just about every chemistry educator uses it as a pivot for their presentation.

In this article I shall step back from our modern perspective, and consider the periodic table in a broader context. I shall also avoid trying to give the impression that I am crafting a micro-textbook of inorganic chemistry as I explore the role of the periodic table in the education of a chemist. Instead I shall aim to pick out some of its more general features and focus on the attitudes about science that it inspires.

First, let me take you back to the early nineteenth century, when only a sprinkling of elements were known and in some sense were also known to be elemental. From that early viewpoint, I think it must have been almost impossible to envisage that there were relations between the elements, and that they were not merely a zoo of disconnected material entities. The supreme achievement of the periodic table is that it showed that the elements were not just a scattering of whimsically created entities, but were deeply and significantly related to one another. I think that someone from the distant past would be astonished to learn that matter was not a collection of islands but more an integrated continent of related entities. Indeed, poor John Newlands was laughed to scorn for his proposal that matter was constituted in musical octaves; but we now know that he was on the right track. The first element of education that the periodic table inspires is therefore that there is an underlying rationality in the fabric of the world. Such an attitude, that of an underlying rationality, pervades all science and should be at the forefront of our strategies of education.

The second feature of the periodic table worth emphasizing, but it hardly needs saying, is the importance of grouping the elements in the pattern the table portrays. Much of science begins with the identification of patterns, and the periodic table illustrates this procedure to perfection. The recognition of patterns is not just the embryo of scientific investigation but is the key to successful education, for it reduces the need for rote memory and facilitates comprehension.

Science, though, is empty-minded if it does not provide an understanding of the patterns it has identified. Charles Darwin's recognition of the pattern of evolution and his formulation of an understanding of it in terms of natural selection is a supreme example of this procedure in biology. The primitive recognition of the eightfold way formulation of a pattern of fundamental particles is an example from fundamental particle physics. The supreme example in chemistry is of course the periodic table itself and its understanding in terms of the electronic structures of the atoms of the elements. Here the central lesson of the table is that it illustrates the interface between inorganic and physical chemistry, the latter providing an explanation of its form and the former providing an unparalleled illustration of its applications.

Even more broadly is the recognition that each division of science identifies its appropriate level of discourse. The eightfold way of physics is at one level; the recognition of species is the appropriate level of discourse in much of biology; and the periodic table reflects the fact that for chemists, the chemical elements, far from being actually elemental, are the appropriate entities for the discussion of much of chemistry. Now the lesson is that it is essential in science to select appropriate entities and to accept that they are *functionally* elemental for the level of discourse intended.

Inorganic chemistry is (to a physical chemist's eye, and probably to an inorganic chemist's eye too) an extraordinarily difficult subject to teach, even with the help of the periodic table, for the table represents not only the systematics of the relation between the elements but also the subtle differences in their personalities. Those personalities demand a different mode of discussion in different regions of the table, with thermodynamic attributes dominant in some regions and structural and perhaps kinetic considerations dominant elsewhere. It is difficult for the student to identify the appropriate mode. Here the existence of the periodic table and the subtlety of the variation of the properties of the elements demands judgement about how to describe and explain, and that in turn entails instilling a flexibility of attitude and a willingness to

adapt. In its unconscious (I think unconscious) way, the very existence of inorganic chemistry and its basis in the periodic table encourages flexibility of mind. Students of inorganic chemistry might not always think that that flexibility is what they are acquiring, but acquiring it they are.

Superficial difficulties of teaching inorganic chemistry, softened and ameliorated by the periodic table, also result in yet another unconscious facilitation of learning and underlie what I think is an important outcome of the education of a chemist: students of chemistry become equipped to be non-chemists. Far from being an admission of failure in our system of education, I regard it as an extraordinary strength and a serious contribution to the economy of a country (and thereby the world at large). I have in mind that in commerce there are few clear-cut solutions. Successful commerce is largely the consequence of taking decisions in a milieu of conflicting influences. In the reality of commercial life, people have to identify dominant influences among many that might be in conflict, and then select the way forward. That summarizes inorganic chemistry, and the fact that a student has been trained to do something similar sets him or her up for being an ideal recruit for commerce. Perhaps the same can be said of students studying history; but the skill that chemists also have, and which is not developed much in history, is the ability to formulate and analyse conflicts quantitatively.

Organic chemistry sits rather uncomfortably in the periodic table, as its principal concern is with a single element, carbon. I wondered about the role of the periodic table in the broader educational aspects of this perhaps most useful (on account of its alliance with medicine and biology) of our branches, and have settled on mediocrity. I am not intending to denigrate organic chemistry by referring to mediocrity; far from it. I have in mind the importance of not being extreme. Carbon is the most mediocre of elements (the interesting etymology of 'mediocrity' is 'half way up a mountain'), being perfectly content to bind to itself, and through being half way up the mountain of electronegativity and related properties, is able to spin out an extraordinary web of compounds. The general lesson—I am dealing only in general lessons in this article—is that when you make room for compromise rather than insisting

on extremes an extraordinary universe of opportunity opens up. The element carbon lies in the middle of the all-important second period of the periodic table, and being neither too electronegative nor electropositive, and having a reasonably compliant electronic structure, is the king of mediocrity, with amazing and extraordinary consequences.

That of course leaves physical chemistry and its role in the periodic table. Given that physical chemistry provides the intellectual infrastructure of chemistry (I don't want that to sound arrogant), our students, enthralled (ideally, but I know I am idealizing) by the fact that the periodic table summarizes so much of the universe, should be entranced by the realization that physical chemistry, particularly through the quantum theory of electronic structure, provides a rationalization of its structure. There is another lesson here, though, which is that of humility. My favourite element, from the point of view of electronic structure, is hydrogen, which well deserves its location at the apex of the table, for through our ability to solve its structure accurately, essentially without approximation, it lies at the heart of the description of the electronic structure of all the elements and therefore the subtle variation that underpins the structure of the table itself. The lesson, though, is the caution that lies in the way of reliable extrapolation. What I have in mind is the doubt I have that the periodic table could have been predicted *a priori*. Maybe a systematic numerical calculation of the electronic structures of all the elements (somehow disregarding the simplicity of the ordinal atomic numbers) might have resulted in the table, but the real strength of physical chemistry in this context has been



displaying the importance of the interplay of empirical knowledge and computational electronic structure. That is its special role in the elements of education in this context, for that interplay emphasizes the importance in chemistry, and not just chemistry but any science, of the alliance of theory and observation. All science is a reticulation of theory and observation, each aiding and guiding the other to result in rich, detailed comprehension.

The periodic table displays other aspects of this interplay, especially through inorganic chemistry, for as I have already stressed, the interpretation of inorganic chemistry shades from structural properties in parts of the table to thermodynamic properties elsewhere, and physical chemistry of course provides the appropriate language and concepts of thermodynamics to bring life to this shading of aspects of interpretation.

The periodic table and the concept of the elements of education inspires all manner of other thoughts. One is the desert-island thought: if you were asked to identify the central elemental concept summarized by the periodic table which, with you isolated on a conceptual desert island and asked to set about rationalizing chemistry, what would it be? My choice would be atomic radius. In molecular biology a common precept is that shape determines function, with shape interpreted as including size, I think that the same maxim applies in the less elaborate region of chemistry. Atomic radius correlates with ionization energy and electron affinity, and thus it correlates with much of the energetics of bond formation. Atomic radius controls perhaps even more than simple energetics the numbers and arrangements of bonds that an element can form, and so is central to considerations of bonding and the formation and stereochemistry of compounds.

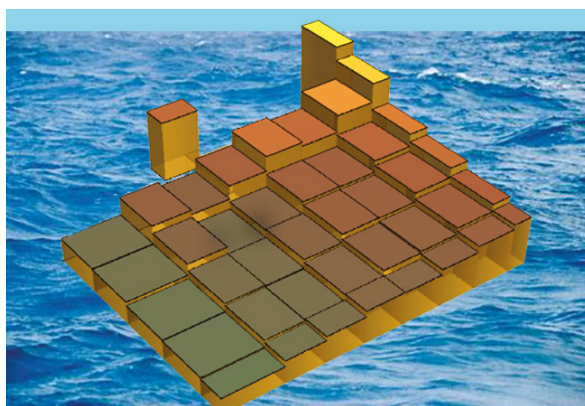


Figure 1: One representation of the periodic table is as a country to be visited, giving the opportunity to discuss its discovery, mapping, and its laws and administration. This is the kingdom of ionization energy.

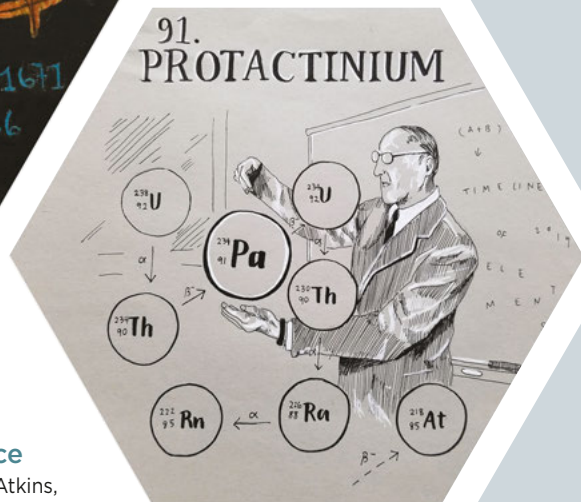
Atomic radius plays a crucial role in the mechanisms of reactions, both in organic and inorganic chemistry, especially in the formation of intermediates and transition complexes. Atomic radius plays a role in the arrangement of electrons around nuclei, as well as that arrangement affecting the radius. When the elements form compounds, the sizes of the constituent atoms affect the size of the molecules and through that size (and the underlying aspects of the energetics of electron excitation, itself size-dependent) the intermolecular forces that determine the physical properties of the compounds. It is hard, in fact, to identify a property that cannot, with sufficiently deep probing, correlate in some way with atomic radius. Function, does indeed follow form and should perhaps be a fundamental element of education.

There are so many aspects of the periodic table that inspire attitudes. One is the continuation of the table beyond $Z = 118$. This prospect inspires the view that chemistry (and science as a whole) is unbounded: as new elements are created (however useless they turn out to be), we have the sense that there is no limit to discovery, which itself should inspire optimism about the scientific endeavour. Then, as we reach into these distant shores of the table, we encounter the role of relativity and the prospect of the decay of periodicity. Relativity, though central to physics, now becomes central to chemistry, and we can, if so inclined, introduce our students to its ramifications at this periphery of our core interests.

The elements of education span more than the education of chemists, for they provide routes into the minds of the general public. Almost every member of the general public has encountered the periodic table; but it is often an icon of horror reminding them vaguely of their dislike of chemistry rather than an exquisite summary of a branch of knowledge. It is a challenge for us to convey its beauty and usefulness and use it to break down the psychological barrier between us and our public. I tried to do this some years ago with my little book *The Periodic Kingdom*, [1] in which I sought to portray the table as a country to visit, with chapters dealing with, among other topics, the discovery of the land, its mapping, and its laws and administration (Fig. 1). Others have developed that simple image into a series of stunning geophysical portrayals of the periodicity of properties. Another tack has been to devise stunning alternative visual portrayals of the table itself, universes removed from Mendeleev's simple workaday list, although few of those beautiful re-imaginings are educationally helpful (I think). Others have spirited the table into other conceptual realms, with

periodic properties of all manner of different concepts. All this is good, for it humanizes the table, keeps it in the public's eye, and thereby brings our subject to the attention of others. All these variously motivated and imaginative entablatures have a common and admirable theme: they encourage people to identify patterns of relationships, which is the germ of science. Anything that encourages imagination should be a core aspect of the education of a chemist, because science in general is imagination in alliance with honesty.

Perhaps there is another dimension to this survey of the elements of education. We chemists spin compounds from elements rather like authors spin sentences from words. The chemical elements are therefore like a restricted palette of words from which sentences are spun by their concatenation and reticulation. The sentences of literature are one-dimensional; our sentences are three dimensional, representing all the matter there currently is and yet to be formed. I suspect that there is little of practical use in that analogy, except that it shows the fecundity of the concepts that the actual periodic table inspires. Its anniversary certainly deserves to be celebrated for its elements, both actual and metaphorical, lie at the core of all present and future chemistry. 🌐



Reference

1. Peter Atkins, *The periodic kingdom*.
Wiedenfeld and Nicolson (1995).

Peter Atkins <peter.atkins001@btinternet.com> was an Oxford professor of chemistry and fellow of Lincoln College until his retirement in 2007. He has written more than 70 books, the best-known of which is *Physical Chemistry*. His other major textbooks include *Inorganic Chemistry*, *Molecular Quantum Mechanics*, *Physical Chemistry for the Life Sciences*, and *Elements of Physical Chemistry*. He chaired the IUPAC Committee on Chemistry Education from 2001 to 2005.

The chemical elements tiles illustrating this feature are part of the IYPT Timeline of Elements project organized by Chem 13 News and the University of Waterloo in Ontario, Canada. See details and credits page 3.



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Montréal
2021
August 13-20

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CCCE
MONTREAL, QC 2021
August 13-20

Elements of Stars

by Maria Lugaro and Ewine van Dishoeck

What are stars made of? Less than 200 years ago this basic, simple question was deemed impossible to answer. As Auguste Comte put it in 1835: *“On the subject of stars...While we can conceive of the possibility of determining their shapes, their sizes, and their motions, we shall never be able by any means to study their chemical composition or their mineralogical structure.”* Today, we have a broad, clear answer to the question: “What are stars made of?” We also understand its far-reaching implications in relation to the evolution of the cosmos. Satellites and many ground-based spectroscopic surveys routinely provide new discoveries on the chemical composition of astronomical objects. In parallel, the nuclear processes that produce the elements inside stars are investigated in increasingly sophisticated nuclear physics experimental facilities across the world. At the same time, supercomputers allow us to calculate detailed models of the evolution of stars and galaxies: how much of which element is produced where? Finally, the presence of tiny amounts of

extra-solar material can be found within meteorites, whose analysis is reaching unparalleled precisions with uncertainties down to parts per million. How have we managed to travel from an impossible question to such broad knowledge filled with discoveries?

Elements of the Sun

Researchers began with the star closest to us, the Sun. In 1813, Joseph von Fraunhofer became the first scientist to systematically study the dark lines seen in the spectrum of the Sun, which were found to coincide with the emission lines of various elements such as H, Ca, Mg and Fe seen at high temperatures in the laboratory. One such line, at 587.6 nm, was originally unidentified and named *helium*, only to be assigned to the actual noble gas element when it was discovered on Earth in 1895.

A major breakthrough came in 1925, when Cecilia Payne-Gaposchkin discovered that the strength of stellar spectral lines depends not only on the stellar surface composition, but also on the degree of ionisation at a given temperature. Applying this discovery to the Sun, she found that C, Si, and other common ‘metals’ seen in the Sun’s spectrum were present in about the same relative amounts as on Earth, however, He and H were vastly more abundant in the Sun than on the Earth. Here the word ‘metal’ is used in the astronomical sense, i.e., any element heavier than H or He.

Meteoritic rocks provide another way to determine the abundances of the Sun. Some primitive meteorites underwent little modification after they formed in the solar nebula and can thus carry accurate information on the elemental abundances of the gas from which the Sun and the planets formed. For example, carbonaceous *chondrites* (Figure 1) are ideal samples because they contain large amounts of organic compounds, which indicate that they experienced very little heating (some were never heated above 50 °C). An extremely close match is found between the elemental compositions derived from the Sun’s spectra and those inferred from the analysis of meteorites. The advantages of meteorites is that their composition can be determined much more precisely than what is possible for the solar spectrum since they can be studied in the laboratory with very sensitive mass spectrometers. In particular, meteoritic analysis can obtain both isotopic and elemental abundances, while isotopic abundances are difficult or impossible to obtain from the solar spectra. However, some gases, such as H and the noble gases are not incorporated into rocks, and some major elements such as C, N, and O do not fully condense into rocks either. For these, we must rely on the Sun’s spectral analysis. For the isotopic composition of



Figure 1. A slice (4.6 x 3.8 cm) from the Gujba chondrite meteorite, which fell in northeastern Nigeria on 3rd April 1984. The round drops are called chondrules and give the name to chondritic meteorites. This meteorite is a special, fascinating case because many of its chondrules are made of metallic iron, rather than silicate minerals. (Image by James St. John from Wikipedia, licensed under the Creative Commons Attribution 2.0 Generic license)

noble gases, on the other hand, the best data come from the analysis of the solar winds.

In 1956, Harold Urey and Hans Suess published the first table of the “cosmic” abundances. Effectively, these were the abundances of the Sun, however, it was then assumed, and as we will see not proven wrong until the late 1950s, that all stars, and the whole Universe as a matter of fact, have the same chemical composition as the Sun. This was the basis of the accepted theory of the time for the origin of the elements, that all of them, from H to Th, were produced together during the Big Bang and their abundances in the Universe were not modified by any further process thereafter. Now we know that the Big Bang only produced H and ^4He , with trace amounts of ^2H , ^3He and ^7Li .

Abundances in other stars

As the quality of spectroscopy observations improved in the 1950s, it started to become possible to identify giant stars that actually show a very different chemical composition from the Sun. These “anomalous” stars showed higher abundances of heavy elements such as Sr and Ba. In 1952, Paul Merrill made a revolutionary discovery; he observed the absorption lines corresponding to the atomic structure of Tc in the spectra of several giant stars. Merrill was at first cautious about this result because the element he identified does not even exist on Earth: being fully radioactive, Tc is only artificially

produced. Merrill showed that stars also produce Tc. Given the relatively short half life of the Tc isotopes (a few million years at most, much shorter than the lifetime of the observed stars), the Tc lines were the first indisputable demonstration that this radioactive element is made *in situ* in the stars where it is observed.

This finding brought a radical change in the way we understand the origin of the chemical elements: the idea that nuclear reactions inside stars are responsible for the production of most of the chemical elements in the Universe began to take shape and garner authority. Today we know that a huge variety of chemical compositions exist among stars and other places in the Universe, with different processes contributing to this diversity.

Images Credits, see page 3.

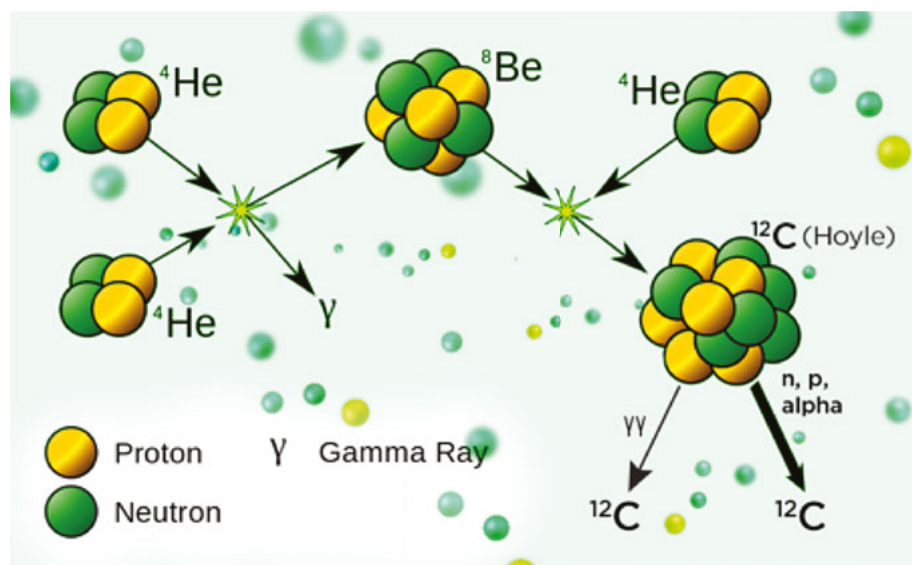


Figure 2. The processes involved in the triple- α reaction that makes carbon in the Universe. Two ^4He nuclei (α particles) create ^8Be , capture of another α particle produces ^{12}C in an excited state at the energy predicted by Fred Hoyle. The excited state decays onto the ground state of ^{12}C by ejecting particles. (Image from National Superconducting Cyclotron Laboratory NSCL, Michigan State University).

Elements of Stars

Nuclear processes in stars

Stellar interiors and explosions are like giant nuclear reactors: the ideal environments for nuclear interactions to happen. Matter can reach extremely high temperatures (for example, 10 million K in the core of the Sun and up to billion K in supernovae) and at the same time a high density is maintained due the force of gravity (for example, roughly 100 gr cm^{-3} in the core of the Sun and up to $10^{10} \text{ gr cm}^{-3}$ in supernovae). Such conditions force nuclei to remain in a confined volume and to react via a huge variety of nuclear interaction channels. This complexity and diversity created all the variety of atomic nuclei from C to Th in the Universe.

The nuclear processes that produce the chemical elements were first systematically organised by Burbidge et al. (1957). Nuclear interactions driven by the strong and weak nuclear force result in fusion, fission, and the decay of unstable nuclei. Complex networks of such reactions can occur depending on the temperature, the availability of the interacting nuclei, and the probability of the interaction itself.

Hydrogen burning activates at temperatures from 10 million K and is responsible for the cosmic production of N by conversion of C and O into it. It also

creates a large variety of minor isotopes, for example, ^{13}C and ^{17}O are produced via proton captures on ^{12}C and ^{16}O , respectively, followed by the fast (order of minutes) decay of the radioactive isotopes ^{13}N and ^{17}F . *Helium burning* occurs from 100 million K and is mostly identified with the “triple- α ” ($^4\text{He} + ^4\text{He} + ^4\text{He}$) reaction producing ^{12}C , with a following α capture on ^{12}C producing ^{16}O (Figure 2).

Because the nucleus of ^8Be consists of 2α particles, it is extremely unstable, and would break before capturing another α particle. To solve this problem, Fred Hoyle predicted that a quantum energy level must exist in the ^{12}C nucleus near the energy where the $^8\text{Be} + \alpha$ reaction would be more likely (a so-called “resonance”). This observation was experimentally confirmed later on and considered as a potential application of the anthropic principle (i.e., that observations of the Universe must be compatible with the conscious and sapient life that observes it) since without this resonance no carbon would exist, and hence no life such as that on the Earth.

In stars with mass below roughly ten times the mass of the Sun, nuclear burning processes do not proceed past He burning. When the nuclear fuel is exhausted, the stellar central region becomes a degenerate, inert

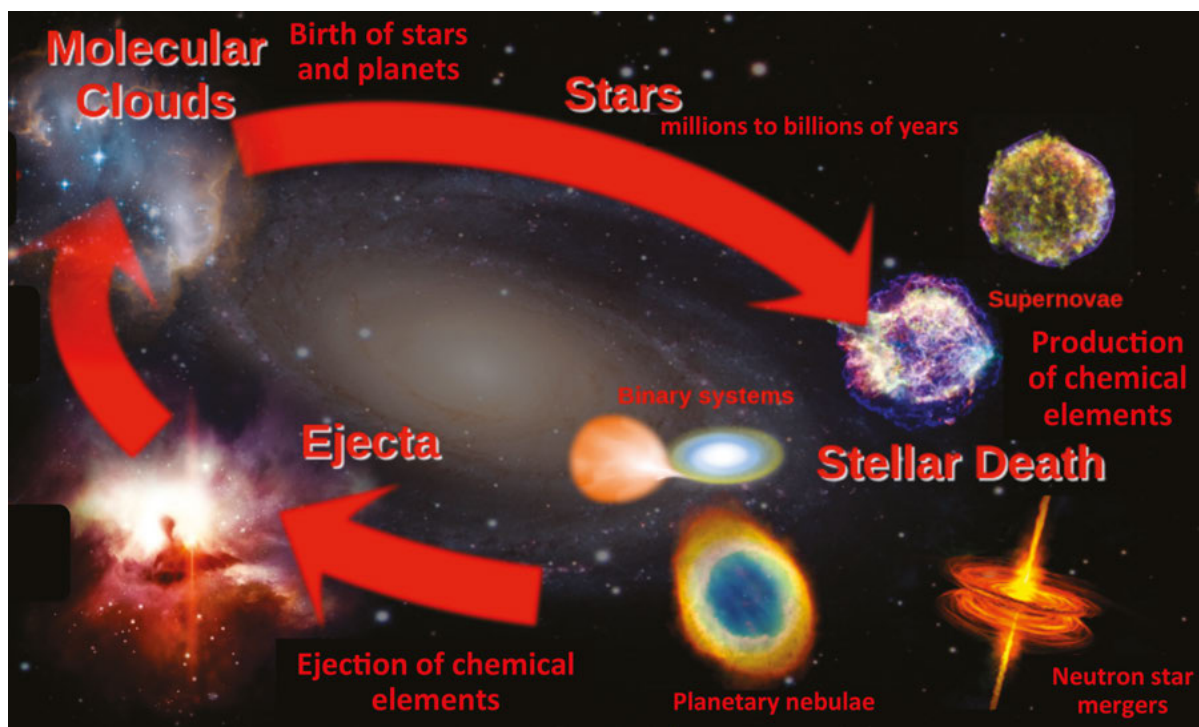


Figure 3. The cosmic cycle of chemical matter in a galaxy. Stars and their planetary systems are born inside cold and dense regions (molecular clouds on the upper left in the figure). Stars can live millions to billions of years: the smaller their mass the longer they live. Chemical elements are produced during the lives of stars and when the stars die, the elements are then ejected back into the galactic gas via winds or explosions. When the gas cools down again, a new generation of stars is born from matter with different chemical composition (figure courtesy of Richard Longland, images from NASA).

C-O core, and H and He continue to burn in shells around the core. In more massive stars, instead, the temperature in the core increases further and a larger variety of reactions can occur. These processes involve C, Ne, and O burning, and include many channels of interactions, with free protons and neutrons driving a large number of possible paths. The cosmic abundances of the “intermediate-mass” elements, roughly from Ne to Cr, are mainly the results of these nuclear burning processes. Once the temperature reaches a billion K, the probabilities of fusion reactions become comparable to those of photo-disintegration and the result is a *nuclear statistical equilibrium*. This process favours the production of nuclei with the highest binding energy per nucleon, resulting in a final composition predominantly characterised by high abundances of nuclei around the Fe peak.

Beyond Fe, charged-particle reactions are not efficient anymore due to the large Coulomb barrier around heavy nuclei with the number of protons greater than 26. *Neutron captures*, in the form of *slow* (*s*) and *rapid* (*r*) processes, are instead the main channels for the production of the atomic nuclei up to Pb, U, and Th. The *s* process requires a relatively low number of neutrons ($\sim 10^7 \text{ cm}^{-3}$) and is at work in low-mass giant stars, producing the Tc observed in these stars. The *r* process requires a much higher number of neutrons ($> 10^{20} \text{ cm}^{-3}$) and occurs in explosive neutron-rich environments. The stellar site of the *r* process has been one of the most uncertain and highly debated topics in astrophysics. Neutron star mergers are now considered as the first observationally proven site of the production of *r*-process elements like gold, based on spectra of the *r*-process supernova (‘kilonova’) associated with the 2017 gravitational wave source GW170817 (Kilpatrick *et al.* 2017).

From stars to the interstellar medium and back

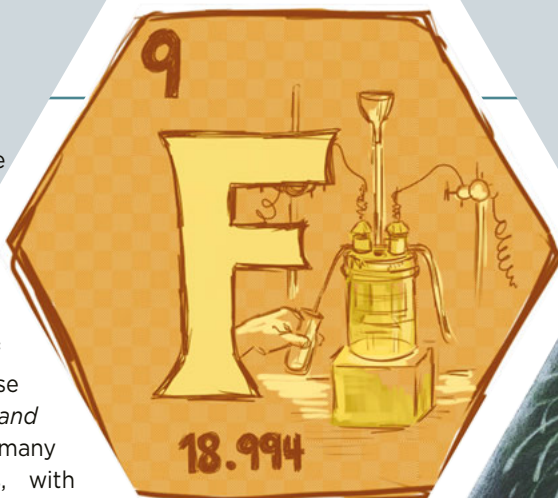
Atomic nuclei created inside stars are expelled into the surrounding medium and recycled into newly forming stars and planets (Figure 3). In stars born with masses similar to the Sun and up to roughly ten times larger, matter is mixed from the deep layers of the star to the stellar surface, and ejected by the stellar winds that peel off the external layers of the star. These processes are most efficient during the final red giant phases of the lives of these stars. When most of the original stellar mass is

lost, the matter expelled by the stellar winds can be illuminated by UV photons coming from the central star, producing what

we observe as a colourful planetary nebula. These stars contribute to the chemical enrichment of the Universe most of the C, N, F, and half of the elements heavier than Fe, the *s*-process element such as Ba and Pb. Eventually the core of the star, rich in C and O produced by previous He burning, is left as a white dwarf.

More massive stars end their lives due to the final collapse of their Fe-rich core. Once nuclear fusion processes have turned all the material in the core into Fe, neither fusion nor fission processes can release energy anymore to prevent the core collapse. As the core collapses, matter starts falling onto it, which results in a bounce shock and a final core-collapse supernova explosion. The exact mechanism of the explosion is not well known although it has been recognised that neutrinos play a crucial role. The supernova ejects into the interstellar medium the fraction of synthesised nuclei that do not fall back into the newly born central compact object: a neutron star or a black hole. The ejected material is rich in O and other common elements such as Mg, Si, and Al.

Binary interaction involving accretion onto a white dwarf can lead to explosive burning and a thermo-nuclear supernova that tears the whole white dwarf apart. These supernovae are responsible for producing most of the Fe in the Universe. Binary interaction between neutron stars and black holes can lead to their merging and, as mentioned above, the production of *r*-process elements like Au.



continued on page 15

Elements of the Future

by Kit Chapman

When Dimitri Mendeleev assembled his periodic table in 1869, the heaviest known element was uranium, element 92. As the table filled, it soon became clear that this was the heaviest element that existed in large quantities on Earth. But it was far from the limit of the building blocks of matter.

For more than 80 years, scientists from across the world have repeatedly pushed past the boundaries of the known periodic table. In doing so, they have replicated nuclear processes usually only found in supernovae or stellar collisions, stretching our known world to 118 elements.

Yet this is only the beginning of what may be possible. As we have honed our knowledge of nuclear physics, the number of predicted elements has swelled. John Wheeler suggested element 100 would be the final piece of the jigsaw; physicist Richard Feynman famously suggested 137. In truth, we have no idea where the periodic table will end. The best guess is that there could be 172 or 173 elements—which would mean we are still yet to discover a third of our chemical universe.

Neutron capture

An element is determined by the number of protons in its nucleus. In theory, to create a heavier element, all you need to do is collide two sets of protons into each other and hope they fuse into a new, heavier nucleus. Unfortunately, this isn't so easy in practice. As protons are positively charged, electrostatic repulsion forms a barrier that prevents them being combined easily.

There are two main methods of overcoming this problem. The first is neutron capture, which involves bombarding a target with neutrons in the hope that these will hit an atom's nucleus. Usually, if a neutron does strike home this results in the nucleus becoming unstable, and simply exploding in atomic fission. Rarely, however, the neutron will be captured by the nucleus and, through beta radioactive decay, a neutron will turn into a proton and move the atom one place up the periodic table.

The first attempts to break past uranium were littered with missteps. In 1938, Enrico Fermi was awarded the Nobel prize for the discovery of elements 93 and 94 using neutron capture. Two months later, a group led by Lise Meitner and Otto Hahn showed that Fermi's supposed elements were the by-products of atomic fission—an idea predicted by Ida Noddack right after Fermi first made his announcement, but subsequently overlooked. Soon after, both Yoshio Nishina at RIKEN

in Japan and Edwin McMillan at the University of California, Berkeley, US, probably saw signs of the true element 93. Nishina was unable to prove it, while McMillan was dissuaded of the discovery by his colleague Emilio Segrè, who went so far as to publish a paper: *an unsuccessful search for transuranic elements* [1].

A year later, McMillan sought a second opinion from colleague Philip Abelson, who soon confirmed the discovery as genuine. Neptunium, element 93, blew the lid off the top of the periodic table, and almost immediately lead to the discovery of element 94, plutonium. With Fermi's help, the first nuclear reactors were built to form cauldrons for neutrons to collide with uranium rods and scale-up the production of plutonium a billion times, enabling its use in the first nuclear weapon.

The neutron capture process can be used to make ever-heavier elements, gradually moving one place up the periodic table with each successful beta decay. But the technique has diminishing returns: as fission is more probable than neutron capture, the odds rapidly stack against you. Today, even specially designed reactors, such as the High Flux Isotope Reactor at Oak Ridge National Laboratory, US, cannot produce large quantities of anything beyond californium, element 98. Indeed, einsteinium and fermium, the heaviest elements first discovered from the results of neutron capture, weren't made in a lab—they were scooped up by fighter planes flying through the debris of the first hydrogen bomb test in 1952, a blast so vigorous it produced some 10^{24} neutrons per cm^2 . While the idea of setting off nuclear explosions in series has been considered as a way to make future elements, fortunately there is an easier and less destructive option.

Transfermium wars

Past fermium, all elements are made a single atom at a time by smashing nuclei together in a particle accelerator. Ions of a lighter element are fired at high speed toward a target with enough energy to overcome the electrostatic repulsion and cause the two nuclei to fuse together. Once again, this usually results in fission—the energy is too great and the nucleus breaks apart. But, occasionally, the nucleus will stabilise. Today's accelerators fire around six trillion ions a second at their targets, with their operators hoping to make around one atom a week.

As these newly created elements are highly unstable, they can only be detected by the tell-tale radiation as they emit alpha particles (two protons, two neutrons) and decay into lighter elements or break apart in fission. By plotting the timing of these alpha particle emissions against the half-lives of known isotopes,

the existence of an element can be proven beyond doubt.

This isn't without problems. Throughout the Cold War, teams from the US and the then-USSR disputed the discovery of elements up to 106, leading to the so-called 'transfermium wars'. For a period of around 40 years, the world effectively had two periodic tables, depending on whether you accepted the Russian or US names. During the 1990s, this resulted in a series of proposed names to try and bring the sides together—the most controversial of which was seaborgium, after US chemist Glenn Seaborg, who was still alive at the time.

Fortunately, such disputes are now in the past, and in collaboration IUPAC and IUPAP have put together guidelines both on what constitutes proof of an element discovery [2] and how an element's name is chosen to prevent any arguments [3]. Any new element must be named after a mineral; property of the element; place; mythical creature or scientist. Sadly, this means the most-requested element name of all time—lemmium, after the lead singer of heavy metal band Motörhead—will never sit on the periodic table. (Unless, of course, you argue that Lemmy is a rock god!)

Hot and cold

When it comes to creating elements through fusion, the choice of beam and target matters. There are two techniques that have proved successful for the heaviest elements. Elements 107 to 113 were discovered by teams in Germany and Japan using 'cold fusion'—combining two elements relatively close together on the periodic table, using just enough energy to squeeze past the electrostatic repulsion. This becomes increasingly difficult as elements get heavier, resulting in greater time between successful hits. The Japanese team that discovered nihonium, for example, needed a cumulative 553 days of beam time spaced across nine years to make three atoms. Cold fusion is simply not a practical option for discovery anymore.

Instead, the current technique used to discover new elements is called 'hot fusion'. Pioneered by a collaboration led by Yuri Oganessian at the Joint Institute for Nuclear Research in Dubna, Russia with Lawrence Livermore National Laboratory, US, this relies on using a relatively light element and firing it into a heavier radioactive target. Neutron-rich isotopes are used so that

neutrons are jettisoned during the reaction, reducing the energy in the nucleus in a hope that this will prevent fission.

An ideal beam for this kind of reaction is calcium-48, which was fired into targets made from plutonium to californium (94 to 98) for the final five elements discovered so far. Calcium-48 has eight extra neutrons compared with the element's most common isotope, a property ideal for hot fusion reactions. It is also 'doubly magic', having complete shells of both neutrons and protons in its nucleus, making it exceptionally stable.

Unfortunately, calcium-48 can't be used to go beyond element 118. Such an experiment would require a target made from einsteinium or higher, which currently can't be produced in significant quantities. This means an alternative beam must be used, which is likely to have a much smaller probability of a successful reaction. Nobody is entirely sure which alternative will work best.

Currently, two teams are in the hunt for the next element. In the red corner, the Dubna-Livermore collaboration will be using a titanium beam to hunt for the next elements using their state-of-the-art Superheavy Element Factory—a new cyclotron accelerator that promises to produce the superheavy elements in greater quantities than ever before. In the blue corner, the team at RIKEN in Japan are using a vanadium beam, and have secured funding to keep searching for the new elements until they are successful.

The most optimistic predictions from the superheavy element community predict that the first glimpses of these two new elements will emerge in the next five years. After that, no one is sure when the next element discovery will come. There is no obvious route



Images Credits, see page 3.



to make element 121 and, until we do, we won't know where it's likely to go on the periodic table—or if the periodic table still applies at all.

The end of periodicity

It's easy to ask why this hunt matters. While some transuranic elements have found important uses—plutonium in power, americium in smoke detectors, curium in medicine—none of the elements beyond californium can be produced in large enough quantities to have practical applications. Why should we care about elements that exist for a split second? Nor is such a hunt cheap. Even ignoring the vast expense of a particle accelerator's operating and staffing costs, one gram of calcium-48 costs around \$200,000. An accelerator uses 0.5mg an hour.

The answer is that these elements unlock fundamental rules of our universe, often in a way that doesn't correspond to expectations. Before the discovery of americium in the 1940s, no one imagined that the actinides would exist: uranium sat under tungsten on the periodic table. Today, physicists argue where element 121 is likely to end up on the periodic table or what its electron configuration may be – does it form a 'superactinide' series or something else entirely? Until we make it, there is simply no way to know for certain.

These aren't purely theoretical discussions. The properties of an element can also be dramatically different than predicted thanks to relativistic effects—alterations in an element's predicted properties due to the theory of relativity, such as gold's colour or mercury's low melting point. These relativistic effects become more pronounced as the elements become heavier, drifting away from periodicity. Current predictions, for example, suggest that oganesson, supposedly a noble gas with filled electron shells, is a reactive solid at room temperature – and may not even form shells at all, but rather carry its electrons around in a Fermi gas [4]. If this is the case, the very structure of the periodic table is called into question.

Sadly, the unstable nature of the superheavy elements makes experimentation difficult, so only the most basic tests can be performed. Even so, one-atom-at-a-time chemistry is possible and has provided a valuable insight into these transient creations. Seaborgium, for example, has been shown to form a hexacarbonyl complex, in line with its homologues tungsten and molybdenum [5]. Flerovium, meanwhile, has been found to be more contentious: while some results suggest it is inert compared with its supposed homologue lead, other findings have hinted at it behaving more like mercury. Currently, researchers are investigating

its properties in rapid experiments, such as capturing the atoms in thiocrown ether rings or passing the atom down a temperature gradient dotted with gold-plated arrays to calculate its enthalpy of sublimation. These experiments will give us a better understanding of the mechanics at work inside the atom.

Finding the island

While these chemical questions are important, the true prize of superheavy element research is the fabled 'island of stability'. First put forward in the 1970s, this idea suggests that isotopes exist with magic numbers of protons and neutrons that could have radioactive half-lives of thousands, perhaps even millions of years.

The best bet for such an island is around element 114, flerovium. Already, the longest-lived isotope known, flerovium-290, is believed to have a half-life of some 19s—far higher than its neighbour moscovium-290's 650ms. However, the centre of the island is predicted to be around flerovium-298. Currently, we are still only on the shoals of stability—and, once again, researchers are stuck. There's no easy way to synthesise such a neutron-rich isotope.

Even so, the long half-lives of flerovium give heavy element scientists hope. If such a long-lived isotope does exist, it is possible it could be found on Earth. Since the 1970s, teams from around the world have looked in some strange places, from the depths of the San Francisco mass transit system and stained-glass windows of Russian churches to moon rocks and the brine shrimp of the Indian oceans. So far, there has been no sign of the elusive superheavies in nature.

As we predict superheavy elements exist in neutron star collisions, researchers have also turned their eyes skywards. Meteorites are so-called 'messengers from space', flying through the cosmos as handy detectors. When something impacts a meteorite, it often leaves a trace in crystals such as olivine. By measuring the depth of these impacts, we can determine what collided with the meteorite. The hope is that eventually one of these olivine traces will show signs of superheavy elements in nature—and, once again, help to hone our understanding of the world we live in. 🌌

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Kit Chapman (@ChemistryKit) is a science journalist based in Southampton, UK. His first book, *Superheavy: Making and Breaking the Periodic Table*, was published by Bloomsbury Sigma earlier this year.

Elements of Stars (cont. from page 11)

continued from page 11

Together, these different processes in different types of stars determine the chemical evolution of galaxies (Figure 3). The next generation of stars forms out of matter of a different composition, depending on the time and place of their birth, and on the full history of their host galaxy. One of the aims of current large (millions of stars) stellar surveys with high-resolution spectroscopy is to derive such chemical diversity and exploit it to understand the formation and history of galaxies within a cosmological framework.

Far-reaching implications

The chemical fingerprints left by the nuclear reactions that take place in stars provide us the opportunity not only to answer the questions of what are stars made of and where the chemical elements come from, but also to study the evolution of the cosmos in a huge range of scales. Observations of the chemical composition of the oldest stars provide us with a glimpse into the early Universe and analysis of the chemical signatures of stellar populations can tell us how galaxies formed.

Closer to home, investigating and interpreting the composition of meteoritic materials and the signature of the nuclear processes left there by different types of stardust provide us with insights on how our own Solar System formed. For example, we now know that the Earth is roughly $1/10^4$ times richer in nuclei produced by the s process in giant stars than Solar System bodies that formed further away from the Sun (Poole *et al.*

2017). How this tiny but robust difference came about in the solar proto-planetary disc is a matter of debate. It represents one of many current questions whose answers allow us to use the chemical elements in stars to understand the evolution of the cosmos, from the Big Bang to life on habitable planets. 🌌

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Elements of Life at the Oxo Wall

by Harry B. Gray

We live on a planet bathed in dioxygen. Iron, the most abundant transition metal element on Earth, reacts with dioxygen to form rust and red clays. It is also an essential component of enzymes that generate the energy we need to live, but alas, many of these reactions can be harmful, leading eventually to destruction of vital organs in our bodies. We can't live without iron and dioxygen, but there are challenges living with them!

Introduction

The top two chemical reactions on Planet Earth are water splitting to dioxygen in photosynthesis and dioxygen reduction in mitochondria during respiration. The elements in the protein machines that drive these reactions are manganese and iron. Both of these elements function in complexes in which the metal center is bonded to an oxygen atom, or more correctly, an oxide anion, in a molecular unit called a "metal-oxo." A manganese-oxo cluster is required for water oxidation in green leaves, producing dioxygen, and an iron-oxo is the active intermediate in dioxygen reduction to water in cytochrome oxidase, the terminal enzyme in respiration [1].

We could not live without proteins that contain iron. Arguably the most important iron protein is cytochrome oxidase, but hemoglobin, which carries dioxygen in our blood, is a close second. In a PNAS Perspective, Kara Bren, Rich Eisenberg, and I retold the 75-year-old (and often very controversial) story of iron-dioxygen bonding in heme proteins [2]. Among the many other iron proteins, myoglobin, which stores dioxygen in our bodies, the cytochrome electron transferases, and the oxidative iron enzymes, deserve special mention.

Of interest in this essay is the oxidative enzyme cytochrome P450, or just "P450." P450 catalyzes the oxidation of a vast array of biologically important organic molecules. When dioxygen reacts with the iron in P450, the powerfully oxidizing multiply bonded iron-oxo formed can break a very strong carbon-hydrogen bond in a hydrophobic molecule, turning it into a water soluble alcohol. Syntheses of many bioactive molecules depend critically on P450 catalyzed oxidations. When the oxidized P450 snatches an electron from the C-H bond, the oxo attracts the C-H proton, forming a protonated oxo and a "carbon radical." The protonated oxo then quickly binds to the carbon radical in a reaction called the "rebound," producing a water soluble alcohol [1].

Ligand Field Theory

How do manganese and iron bond to oxos? And how do these metal oxos function in biological reactions? The story starts early in 1961, when I was working with Carl Ballhausen, a professor at the University of Copenhagen. I had shown in the fall of 1960 that the crystal field theory could not account for the energies of absorptions in the near infrared and visible spectrum of the nickel aquo ion. As it was clear to me that a better theoretical framework was needed, I decided to modify Robert Mulliken's molecular orbital (MO) theory, which was good for organic molecules but had given crazy results for inorganic ones. I invented a way to correct the diagonal energy elements so MO calculations gave one-electron orbital energies in accord with experiment. Then I picked an oxo of vanadium, the vanadyl ion, to test this "Ligand Field Theory." My calculations were successful, accounting not only for the vanadyl absorption spectrum, but also for its magnetic and reactivity properties. I wrote two papers on ligand field theory, one with Ballhausen, another with Curt Hare, in which I showed that oxos form triple bonds to vanadium, chromium, and molybdenum [3,4]. And I predicted that protons would not be attracted to triply bonded oxos, rather that nucleophilic reagents likely would react with them. It is of interest in this context that one of the proposed mechanisms of dioxygen evolution during photosynthetic water oxidation features hydroxide attack on a triply bonded Mn-oxo [5]. But there are other proposed mechanisms, some with substantial support from both theory and experiment, so the dust has not settled yet on this important area of science.

The Oxo Wall

In teaching inorganic chemistry at Caltech, I always have emphasized that early transition metal elements react with dioxygen to form multiply bonded metal-oxos. I have discussed the bonding in metal-oxos every year, with emphasis mainly on the vanadyl ion. One year I decided to add tetrahedral oxos such as chromate and permanganate to the story. In preparing for class, I remembered from searches I had done in Copenhagen that there were no stable tetraoxos of transition metal elements beyond the iron-ruthenium-osmium column in the periodic table. Nor were there any tetragonal metal-oxos past that column. I consulted my tetrahedral and tetragonal ligand field energy diagrams, discovering that I had predicted that strongly bonded metal-oxos could not exist if there were more than two π -antibonding electrons. On that very day I told the class that there must be an "oxo wall" between

the Fe-Ru-Os and Co-Rh-Ir triads in the periodic table (Figure 1)!

My oxo wall lecture was a highlight every year in the course. I decided to take it public, giving “oxo” seminars at universities and at ACS meetings. For years the only “oxo wall” publications were ACS abstracts (Jay Winkler and I have corrected that oversight [6,7]). But these were enough to energize inorganic chemists to search for violations. The search came up empty until a well-known investigator reported in *Science* that he had made a tetragonal Pt-oxo compound. I knew that a Pt-oxo would be a violation! I was relieved when he sent me an email saying that he was retracting his claim, as upon further study, it turned out that his platinum-oxo was in fact a tungsten-oxo, which was on the left (allowed!) side of the wall. He did me a great favor when, in the title of his “tungsten-oxo” paper, he wrote, “The Oxo Wall Stands” [8].

Nature knew about the oxo wall when she picked elemental metals for the generation and reduction of dioxygen. In their reaction cycles, manganese in photosystem II and iron in cytochrome c oxidase and P450 form multiply bonded metal-oxos with dramatically different properties (Figure 2). Metal-oxo electronic structure is key: a protonated triply bonded Mn(V)-oxo is a super acid, with a pK_a less than -10. Such a highly acidic oxo could attract an oxygen donor, which in turn would promote redox-coupled O-O bond formation. In contrast, the combination of two π^* electrons and

an axial cysteine thiolate combine to make the doubly bonded Fe(IV)-oxo of P450 compound II very basic, with a pK_a of about 12. It is widely recognized that the generation of such a basic Fe(IV)-oxo is an essential step in the catalytic cycle of P450 [7,9].

Cytochrome P450: Good or Bad?

Mike Green, a professor at UC Irvine, has pointed out that compound I of P450 would be able to extract an electron from a C-H bond only if coupled to proton transfer to a newly formed Fe(IV) oxo of compound II. He has shown that the high reduction potential of compound I and the basicity of compound II together provide the driving force for the reaction [9,10]. In this reaction, the newly formed hydroxyl and carbon-centered radicals rebound, making a C-O bond in forming

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	Lu	Hf	Ta	W	Re	Os		Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn

Figure 1. There is an oxo wall between Fe-Ru-Os and Co-Rh-Ir in the periodic table. There are no multiply bonded (tetragonal) metal-oxos with more than 4 d electrons, in accord with the predictions of ligand field theory. Multiply bonded metal-oxos beyond the wall cannot exist, as the metals in the high oxidation states required [for example, Co(V) or Ni(VI)] would be rapidly reduced in an oxo ligand environment.

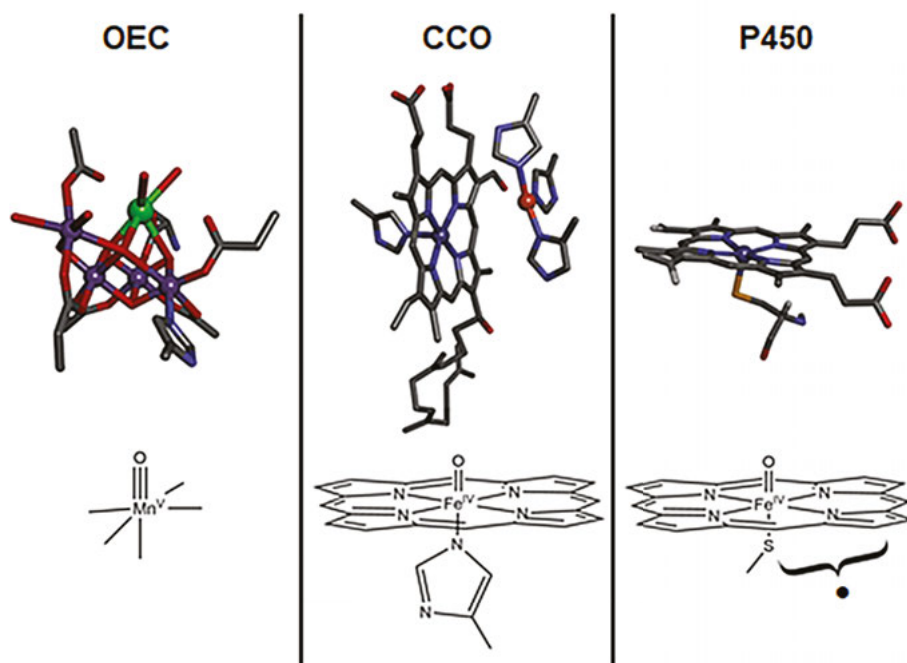


Figure 2. Manganese oxos in the oxygen evolving complex (OEC) of photosystem II catalyze water oxidation to dioxygen; an axial histidine-ligated iron-oxo in cytochrome c oxidase (CCO) is a key intermediate in dioxygen reduction during respiration; and an axial cysteine-ligated P450 compound I iron-oxo converts hydrocarbons to molecules that are critical for life.

the product alcohol, along with return of the heme iron to its resting (ferric) state. The million dollar question then becomes, what happens if the substrate is not oxygenated? If the powerfully oxidizing compounds I and II are generated in the absence of substrate, what keeps them from destroying the proteins (and the cells) they occupy [11]?

In the P450 reaction cycle, the heme iron in the resting enzyme is in the 3+ oxidation state. Substrate binding in the heme pocket displaces an axial water ligand, resulting in a positive shift in the $\text{Fe}^{\text{III/II}}$ formal potential. This increased oxidizing power favors electron delivery from cytochrome P450 reductase to produce the Fe^{II} state, which is followed by dioxygen binding to produce an Fe^{III} superoxide complex. Delivery of a second electron from the reductase induces O-O bond scission, forming water and the hydroxylating agent, iron-oxo compound I. Hydrogen atom abstraction from the substrate generates iron-oxo compound II and a substrate radical; hydroxyl rebound produces the product and water ligation regenerates the enzyme resting state [1].

During cytochrome P450 catalysis, one molecule of O_2 is consumed for each molecule of product formed. The human liver enzyme known as CYP3A4 metabolizes many therapeutic drugs; and it couples O_2 consumption to substrate oxidation, but with only 10% efficiency [12]. In 2014, Jay Winkler and I proposed that redox chains comprised of tyrosine and tryptophan residues (Tyr/Trp chains) could protect the enzyme from

damage by compound I when reaction with substrate does not occur [13]. We proposed that these Tyr/Trp redox chains could guide oxidizing equivalents (called “holes”) away from the critical active site, taking them to the enzyme surface where they could be scavenged by soluble reductants such as glutathione and ferrocytochrome b_5 . In search of support for our proposal, we examined thousands of X-ray crystal structures in the RCSB Protein Data Bank (PDB), finding that Tyr/Trp chains occur prominently in oxidoreductases [14]. Based on this finding, we suggested that there is an internal antioxidant protection mechanism involving long-range electron transfer from Tyr (or Trp) to the heme iron, where the internal antioxidant time constant is determined by the distance from the heme to the nearest Tyr/Trp residue. If the P450 iron-oxo fails to oxidize substrate within the prescribed time limit, electron transfer from the Tyr/Trp chain would rescue the enzyme by regenerating the ferric resting state.

We found that Tyr/Trp-to-heme distances in P450s are often in the 7-8 Å range. Of interest is that many structurally characterized eukaryotic P450s are mammalian enzymes where, in each case, a tryptophan is hydrogen bonded to a heme-propionate. The tryptophan in question in human CYP3A4 is Trp126, located 7.2 Å from the heme and 4.7 Å from a surface exposed tyrosine, Tyr99. In this enzyme, there is a potential protection pathway involving hole transfer from the heme to Trp126, then moving on to Tyr99. Based on multistep electron tunneling times from previously constructed “hopping

maps," we estimated that the iron-oxo of CYP3A4 compound I would be reduced by Trp126 in 200 ns if substrate oxidation did not occur more rapidly [7]. In this scenario, the Tyr99 radical generated by hole hopping from Trp126 would react with soluble reductants such as glutathione. Trp 126 sends a very clear message to the heme: "Look, if your iron-oxo doesn't oxidize the substrate, I am going to reduce you!"



Parting Shots

We have been living with dioxygen for over two billion years. Manganese plays a key role in generating dioxygen, and iron enzymes use it to make compounds critical for human life. But dioxygen is toxic, and Nature has had to evolve protection mechanisms to keep us alive! 🦎

Acknowledgment

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The chemical elements tiles illustrating this feature are part of the IYPT Timeline of Elements project organized by Chem 13 News and the University of Waterloo in Ontario, Canada. See details and credits page 3.

Elements of Technology

by Michael Droescher

There are many ways to look at the periodic table. When Mendeleev established the table, he arranged the elements according to atomic number and chemical properties. Here, we try a different look. We discuss the influence and links of elements on the development of cultures and technologies. Some of the elements have a direct impact on our life: carbon, nitrogen, hydrogen, oxygen and phosphorous are the main building blocks of our organism, besides small amounts of other elements. Many other elements, especially metals, are the base of the development of our social and technological world, due to the availability and/or innovative use of new or already known elements. We will have a look on the relevance and importance of these elements for the development of technologies over the last 10 millennia.

We learned in history class that early humans were using materials they found in the environment, as wood, stones, fibers, bones, etc. We call this time period the Stone Age. But about 10 000 years ago, new materials became available. Extracting metals from the earth, first copper and tin for bronze and then iron, were disruptive innovations and became the base of a dynamic growth of population and technologies. There was also gold in the form of nuggets found in nature, as there is evidence of gold in Egyptian history 5000 years ago. But in those days, gold was not relevant for technology; it was a symbol of wealth. It is said that the upper stones of pyramids in the middle dynasty in Egypt were covered with gold. Silver is also reported to be mined about 5000 years ago. Again, in those times, it was used for its value in coins or jewelry rather than as a material. Both gold and silver became important for technologies much later, as we will see below.

Let us begin in the Bronze Age. First, mankind learned to extract copper from copper ore and used copper directly. But tools and weapons made from copper were quite soft. Soon it was discovered that smelting copper together with tin or arsenic would yield better materials, what we call alloys. These materials are harder and stronger than the pure metal. Building a wide knowledge of mining various ores and learning to smelt these ores into metals and alloys gave rise to many new technologies. Also, increasing trade led to a strong interaction of cultures in South Europe, Asia Minor and North and Sub-Saharan Africa. Ingots of copper or tin are still found today in ancient trade shipwrecks on the ground of the Mediterranean Sea.

The first surviving iron artifacts, from the 4th

millennium BC in Egypt, were made from meteoritic iron-nickel. One of the first smelted iron artifacts, a dagger, dates back to a tomb in Anatolia, dated about 2500 BC. It is not known where or when the smelting of iron ore began, but by the end of the 2nd millennium BC iron was being produced from iron ores from Sub-Saharan Africa to China [1]. The development of ferrous metallurgy technology would be a thick book of its own. Here, we will just mention that iron materials always contain carbon, which comes from the charcoal, today coke, used to reduce the ore. Cast iron has high carbon content. To produce steel, the carbon content has to be reduced. There was a long technology development from the first cast or pig iron to the modern thin steel sheet, used to build cars. For example, it takes many steps to forge a Japanese chef knife or a Saracen sword, both with a complicated structure of different layers of steel with different carbon content and structure.

Whereas bronze and iron were materials for tools, weapon or construction, we move on to the 15th century when we see a revolution in communication. Lead was already being used in many applications, such as plumbing. It melts quite low at 327°C and is easily formed. In the 1450s lead became the means for a revolution of communication when Gutenberg invented movable types. Before, books had been written by hand or printed by using printing plates cut from wood. Movable metal types, cast from an alloy of lead, tin and antimony, made the difference. Books and leaflets could be produced much cheaper and in larger numbers. This was clearly revolutionizing communication structures, and led to the success of Martin Luther's reformation process some 60 years later.

Silver, before mainly used for coins and tableware and other household tools, played an important role in the next communication revolution, when photography was invented. In the process developed by Daquerre in the 1830s, silver was applied in the form of halides to capture the light. In the beginning, the exposure times of the glass plates took some minutes. Films were introduced in the late 19th century. I still remember my own square 8 x 8 cm black and white photos from the 1960s. Then, the film was taken out of the simple camera, put in a small light dense container and developed by a specialist nearby. A film had 12 to 20 exposures and required careful selection of subjects. As we all know, digital formats have taken photography. Today, we shoot hundreds of images on our smartphones without such care in selecting a subject.

Let us go back into the 18th century and look at the industrial revolution induced by the invention of the

steam engine. Without access to materials like modern steel and cast iron, Thomas Watt would not have invented this important tool. And perhaps England would have more forest today, as most of the wood available at the time was turned into charcoal to smelt iron ore. Later, coke from coal was used as reducing agent. Steel was always needed in large quantities.

A new means of transportation to fuel the economy, the railway, was invented. In the German and French words for railway, *Eisenbahn* and *chemin de fer*, the importance of iron for the development of the infrastructure is still present.

The next revolution focused on warfare and agriculture. Nitrogen, in the form of N_2 , is the most abundant uncombined element. Nitrates are used in explosives and more importantly, ammonia in fertilizer. Until 110 years ago, nitrates were only available from deposits and ammonia from electrolysis. Only when Haber and Bosch developed a new synthesis process for ammonia in 1909 could large scale production be started. This first helped Germany in World War I to overcome the blockade of saltpeter from Chile, but much more importantly fueled the agricultural revolution by providing synthetic fertilizer in previously unknown capacities and volumes.

Carbon, now in the form of organic materials, is the topic of the next industrial revolution, synthetic organic materials. Today most of the fossil carbon, about 90% of the coal, gas and oil extracted from earth, ends up as CO_2 from combustion processes. Only about 10% of the fossil resources are used to produce synthetic organic materials, which have to a large extent replaced natural materials like wood or wool. In the beginning of the 20th century coal was the raw material base. After World War II, raw oil became the fuel of the new and fast growing global economy. Today, natural gas and renewable raw materials are gaining increasing importance as feedstock. Synthetic organic materials, as plastics, thermosets, coatings, foams, synthetic textiles, make up most of the materials we use. And we use large volumes. About 335 million metric tons of plastics are produced annually [2].

Elemental carbon in the form of diamond was always used as jewelry. Synthetic diamonds became available with high pressure synthesis technologies and are used as polishing material, being the hardest material of all.



Graphite has many uses, such as electrodes. In the late 19th century carbon fibers were used in the first light bulbs, soon to be replaced

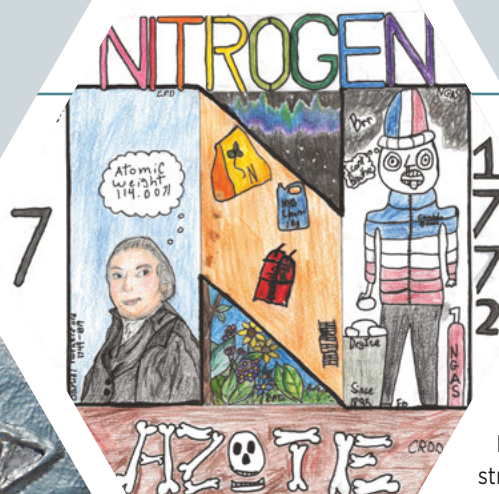


by tungsten, which was much less prone to breaking. Today, carbon fibers are the base of lightweight materials, such as for the construction of airplanes or the cockpit of Formula 1 racecars. Recently, two-dimensional elemental carbon structures, graphenes, have been developed into new materials with a hope for application in electronics.

The next revolution was based on sand, or silicon dioxide, the source of purest silicon. Silicon is a semiconductor material, it conducts electron holes and electrons. Thus, it became the workhorse of electronic structures. Processes had to be developed to produce 99.999999% pure silicon with a mono-crystalline structure. From these crystals wafers are cut on which the integrated circuits are modeled. I remember my first transistor radio from 1966 and write this article on a laptop produced in 2018. In this timespan the number of microprocessors in an integrated circuit has grown from a few to over 20 billion. Digitalization, the buzz word of today, started in the 1950s and has changed our life and communication, much as the printing press with movable letters did 500 years ago.

Electronic devices need a surface to use easily. Up to the 1960s computers were programmed and fed with data from punched cards. We had to punch and carry hundreds or even thousands of cards to the computer center of the University of Mainz in 1970. In the 1970s computers were fed information via a keyboard. Today we use touch screens. Here, the metal indium comes into the focus. It was first used to produce flat screen television sets, where thin layers of

Images Credits, see page 3.



light emitting diodes, which have by now taken the lead in lighting applications around the world. Again, new materials opened the route to wider application. Blue LEDs were difficult to construct until gallium nitride crystals were made available. As electric mobility and the investments in windmills

grow, the need for permanent magnets is also growing rapidly. Neodymium magnets are the strongest permanent magnets known. A list of the application of the various rare earth elements in modern technology would fill another paper. Here, we can conclude, that modern technologies need half of the elements in the periodic table. And, although not all so-called rare earth elements are really rare, we must be very careful with our resources.

This is also true for the smallest noble gas. Helium is, after hydrogen, the second most abundant element in the observable universe. However, helium gas escapes into space when released to our atmosphere. Helium is needed to cool down many appliances, for example the superconducting magnets in magnetic resonance imaging scanners.

We have to acknowledge that most of our resources are limited. For the first time in history we might run out of some of the elements necessary to keep our technologies alive. Therefore, we should make sure that all elements and materials which are brought into the technical sphere will not disappear in landfills or other depots after application and use, but should be recycled and brought back into the value cycle. 🌱

liquid crystal materials are switched in an electric field, built up between the pixel structure in the back and a transparent and electric conducting indium tin oxide layer in front. Today touch screens are everywhere in our life, from household appliances to our cars and all hand-held communication tools.

This brings us back to gold, which continues to be a sign of wealth and power for 10 000 years in the form of coins, ingots and jewelry. As gold is a very good conductor material, it is employed in the electronic structures of our smartphone, laptops, or any other electronic device, together with a large number of other elements. Have a look on the video of Arjan Dijkstra and Colin Wilkins of the University of Plymouth in the U.K. They used a blender to reveal what our smartphones are made of. The experiment was designed to highlight the rare mineral resources used in our everyday electronic devices. They discovered that the phone used in the tests contained 33g of iron, 13g of silicon and 7g of chromium. It also contained other important elements, including 900mg of tungsten, 90mg of silver, 70mg of cobalt, and 36mg of gold [3].

Modern technologies always make use of a large variety of ingredients. For Li-ion batteries, besides lithium, which is extracted from salt lakes in countries like Bolivia or Chile, cobalt is an important element. Here, the political stability of the source of the ore in the Democratic Republic of the Congo and Zambia is of some concern.

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Elements of Scarcity

by David J. Cole-Hamilton

We used to chant a rhyme when we were young (I had three dominant sisters and no brothers!): “What are little girls made of? Sugar and spice and all things nice. What are little boys made of? Slugs and snails and puppy dog’s tails.” The truth is, of course, that they are all made from the same things, as is everything around them that makes up our diverse and beautiful world as well as much of the universe—the 90 natural elements that are the building blocks of life. It is an amazing thought that these are *only* building blocks so it is essential that we should nurture and cherish all of them if we are to continue to enjoy life in its abundance.

That is why the European Chemical Society, EuChemS, has decided to celebrate the *International Year of the Periodic Table* by designing and releasing a new version of the Periodic Table which highlights these 90 elements (Figure 1) [1]. It has been designed with the aim of placing it in every age-appropriate school in Europe and already many countries are delivering poster sized versions to schools. Following its launch in the European Parliament by Catherine Stihler and Clare Moody MEPs, it has achieved publicity in at least six continents.

The Periodic Table

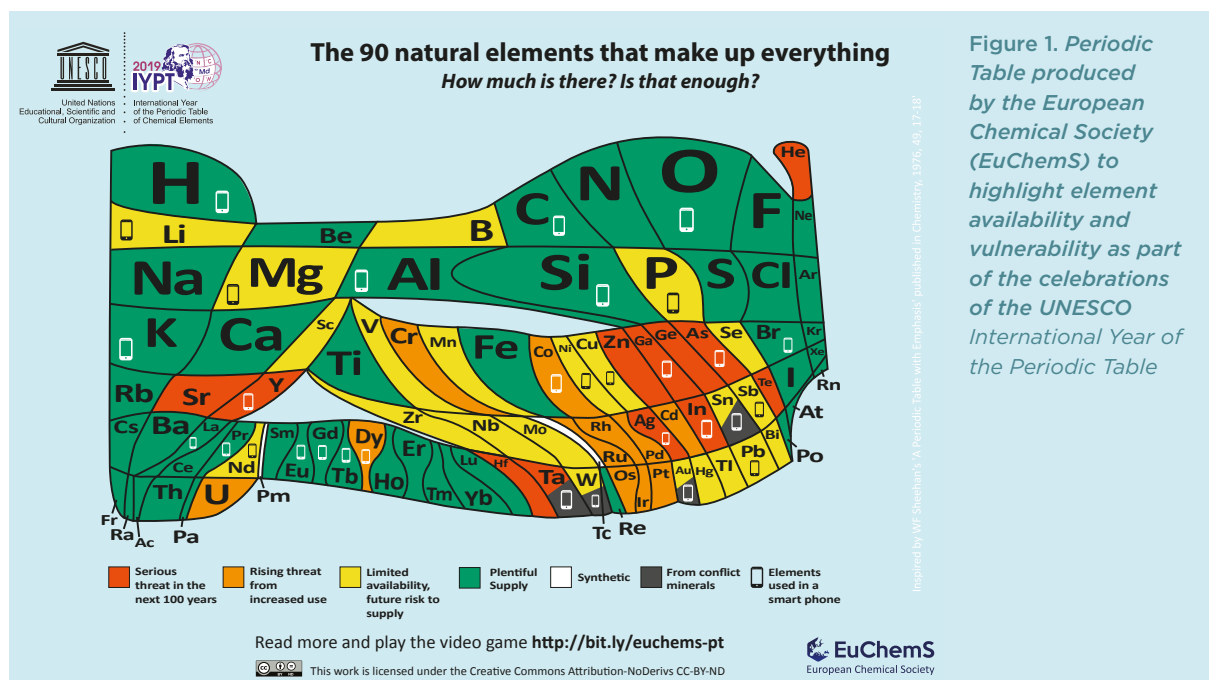
The Periodic Table is something almost everyone has seen during their school education. To chemists it

is beautiful summary of the whole of chemistry, which can be used to predict the properties of elements and to direct new research aimed at developing important new compounds and materials with amazing properties, as summarised in many of the other chapters of this issue of *Chemistry International*.

To the general public, however, the Periodic Table (Figure 2) is at best a curiosity and a worst a reminder of boring days in classrooms where it hung forlornly as an obscure grid on the wall. This is why the EuChemS Periodic Table appears so different from a normal periodic table. It has been designed to catch the eye so everyone will ask “What is that?” As soon as that question is asked, interest is aroused and people will dig more deeply to understand more.

Element availability

In the EuChemS Periodic Table, the area occupied by each element is proportional to the amount of that element in the earth’s crust and in the atmosphere (this only affects nitrogen) [2]. The scale is logarithmic (log megatonne atoms) since the less abundant elements would be invisible on a linear scale. Even so, we have had to enlarge some of the smaller ones so they can be seen. The very different amounts of the elements leads to a Periodic Table with humps and sweeping curves rather than a grid of straight lines. It also allows the lanthanoids (lanthanum to lutetium) to be placed in their rightful position. The overall shape is based on an original idea of J. F. Sheehan, [3] as modified by K.



Elements of Scarcity

A. Carrado, [4] but the areas all had to be redrawn to obtain the right relative sizes.

The transuranic elements have all been omitted because none of them occurs naturally to a significant extent, although plutonium, which is present in trace amounts in natural uranium, is now available in quite high quantities as a byproduct of nuclear power generation. Technetium does occur in small amounts in the earth's crust, and is extensively used in medical imaging but all of that is prepared in the laboratory from a radioactive isotope of molybdenum.

Element vulnerability

Of course, the amount of an element that is available does not tell us anything about whether we should be worried about its supply. This also depends on the extent to which it is used and whether or not it is recycled.

The EuChemS Periodic Table colour codes [5] each element to indicate how long it will last if we continue to use it at the rate we do at the moment. With one exception, elements are not lost to us, they are dispersed more widely and become more and more difficult to collect and supply. In the Table, elements coloured red are expected to be dispersed within 100 years whilst those in green are plentifully available, in some cases being recycled by natural processes. Orange and yellow colour elements that may become vulnerable as we use them more.

Four elements—tin, tantalum, tungsten, and gold—are partially coloured black. These are elements that come from mines where wars are fought over the mineral rights or where profits from the mines fund wars. Most of these are in the Democratic Republic of the Congo. These elements also come from other places so care must be taken to ensure that samples used in manufacturing do not come from these mines. Traceability is the process by which ores are tagged and traced throughout

their life from the mine through all the processing steps to the final manufacture of a device. It is also being extended to the fate of that element after the end of the useful life of the device. This is crucially important to ensure that we do not have elements in our pockets from places where people have died to extract them.

Elements in a smart phone

31 of the elements in the EuChemS Periodic Table bear a smart phone symbol because they are used in manufacturing most smart phones [6]. Overall, there may be as many as 70 that are used in one smart phone or another. A smart phone has been chosen because almost everyone has one or more but it is representative of many other common electrical goods like laptops, tablets, etc.

Amongst the 31 elements in the smart phone, six are expected to be dispersed within 100 years and all four elements from conflict minerals are included. This is why traceability is so important in the smart phone industry and most manufacturers do try to make sure they know the origin of these elements.

At present, an astonishing 10 million smart phones are exchanged in Europe **every month**; 12 million in the USA. Think about the amounts of these scarce elements that represents and then think about what happens to them. A very significant percentage of used phones are kept in drawers by their owners (> 50% of UK homes have at least one) [7] these elements are lost to society. The rest are sometimes re-used but eventually end up in the developing world. There, artisanal miners, often children, try to extract the gold from them using strong acid, sometimes in open pools in the street. The remains of the phones are piled up by the roadside or sent to landfill.

Let's take a look at a couple of examples of elements in your phone:

1	H	2	He																																																																																																																																				
3	Li	4	Be	5	B	6	C	7	N	8	O	9	F	10	Ne																																																																																																																								
11	Na	12	Mg	13	Al	14	Si	15	P	16	S	17	Cl	18	Ar																																																																																																																								
19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co	28	Ni	29	Cu	30	Zn	31	Ga	32	Ge	33	As	34	Se	35	Br	36	Kr																																																																																																				
37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh	46	Pd	47	Ag	48	Cd	49	In	50	Sn	51	Sb	52	Te	53	I	54	Xe																																																																																																				
55	Cs	56	Ba	57	La	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200
57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu	64	Gd	65	Tb	66	Dy	67	Ho	68	Er	69	Tm	70	Yb	71	Lu	72	Hf	73	Ta	74	W	75	Re	76	Os	77	Ir	78	Pt	79	Au	80	Hg	81	Tl	82	Pb	83	Bi	84	Po	85	At	86	Rn																																																																												
89	Ac	90	Th	91	Pa	92	U	93	Np	94	Pu	95	Am	96	Cm	97	Bk	98	Cf	99	Es	100	Fm	101	Md	102	No	103	Lr																																																																																																										

Figure 2. A standard Periodic Table, although this one is made by the technique of macramé by Jane Stewart for the International Year of the Periodic Table. It consists of 200,000 knots. Photograph courtesy of Helen Stewart.

Tantalum (Ta)

Tantalum can come from conflict minerals and the amount available is enough for less than 50 years at current usage rates without recycling. It is used in microcapacitors because the highly dielectric constant of tantalum oxide means that very thin films are efficient insulators. Each iPhone has one tantalum based capacitor on the mother board containing 2 cents worth of tantalum. That does not sound like much, but remember the huge number of iPhones in circulation (> 40 % market share). In the period 2001-2006 only about 1 % of the tantalum used was from conflict zones. As tantalum is dispersed and the price from non-conflict sources increases, the temptation to break the taboo and use material mined in conflict zones will increase.



Images Credits, see page 3.



in the sea off Japan in 2018. These deposits appear to be sufficient to supply our needs for many years to come.

Indium (In)

Indium is a component of indium tin oxide which makes up the conducting layer in every touch screen. It is used in cold welding of electrical circuits, in lasers and detectors for telecommunications, and in blue lights. Indium is a by-product of zinc manufacturing and there is only enough from this source for 20 years if we continue to use it at the current rate. After the zinc-related source is used up we shall still be able to acquire indium from other ores, but its concentration is lower and so the extraction price will be higher.

Cobalt (Co)

Cobalt is used in the lithium batteries that power so many of our devices and an increasing number of cars. Increased use could become a major cause for concern in years to come. More seriously, cobalt has not yet been classified as a conflict mineral. However, some of it comes from the Democratic Republic of the Congo, where it is mined under appalling conditions, often by children. As demand increases, it will be essential to use traceability to ensure that cobalt is not obtained by exploiting child labour.

Rare earth elements (lanthanoids)

Many of the lanthanoids are used to provide the bright coloured light emitters of a smart phone display, yet most of them are coloured green in the EuChemS Periodic Table suggesting that they are in plentiful supply. This is because large deposits of these elements were discovered

The one exception is dysprosium which does provide coloured emitters for phones but is coloured orange on the Table because it has another very important use— in the magnets which allow windmills to convert wind energy into electricity. The climate crisis caused by global warming means that we must urgently reduce CO₂ emissions from burning fossil fuels. To do this the use of windmills must increase and with it the consumption of dysprosium.

Helium (He)

The one element that can be lost rather than just dispersed is helium. It is the second lightest element and is very stable, being an inert gas. This means that if it is released it floats slowly up to the outer edges of the atmosphere then escapes the earth's gravitational pull and is lost into outer space forever. Helium is the second most abundant element in the universe, being the first and main product of nuclear fusion in stars, as discussed elsewhere in this issue. On earth, it is a different story. Helium is formed by the decay of radioactive nuclei in rocks and much goes straight to outer space, as described above. The rest collects in underground caves mixed with other gases.

Helium boils at 4° above absolute zero and provides the only liquid cold enough to cool the superconducting magnets in MRI scanners. This is its main use but other uses include weather balloons, inert atmospheres for semiconductor processing, lifting, and as a partial replacement for nitrogen in the air breathed by deep sea divers to avoid nitrogen narcosis. In most of these

applications, the helium is recycled, but the main one where it is not is when helium is used in party balloons, which take up about 10 % of helium. They either go down or burst and the helium is lost forever. Does this matter?

There are three main suppliers of helium, Qatar, whose fields are closed; the USA which will cease supplying in 2021; and a new field that has been discovered in Tanzania which will begin supplying in 2020. The Tanzanian field contains enough helium for 8 to 12 years at current usage rates if none of it were recycled. Recycling extends that horizon dramatically. However, if 10% of the helium from the Tanzanian field, the only significant one we currently know about, is lost every year, **ALL** of it will be gone in 80 to 120 years and there will be none left for MRI scanners. It is argued that the helium used in balloons is relatively impure at 95 % so uneconomical to purify. However, the Tanzanian field has less than 10% helium and that will be purified.

Phosphorus (P) and magnesium (Mg)

Phosphorus and magnesium are relatively abundant elements which are coloured yellow on the EuChemS Periodic Table, meaning that there could be problems of supply as a result of increasing usage in the longer term.

The problem here is the way we use them. Magnesium is at the centre of chlorophyll, which gives the green colour to leaves and is responsible for converting CO₂ and water to sugar and the oxygen we breathe. Without it there would be no oxygen and no life. Phosphorus mainly comes from Morocco, where there are large deposits of phosphate rocks. It is used as phosphate in fertilisers.

In both cases they form part of the diet of humans and animals so they pass into the food chain. We either eat the plants directly or eat animals that have eaten plants. This means that the essential nutrients including magnesium and phosphorus are taken out of the soil and end up in human cadavers but mostly in human sewage. After processing they are flushed into the sea. As the population increases we flush more and more of the phosphorus and magnesium into the sea and less is available for growing plants.

What can be done—what can WE do?

The EuChemS Periodic Table has been designed to highlight a current and potentially growing problem, but it is not designed to force people to sit and wring their hands in despair. In the end, it provides a message of hope. **It is not too late if we act now.**

The Periodic Table provides a clarion call to start acting now and introduce a circular economy, which

reduces the amount of precious elements that we use, recycles these precious elements, repairs rather than replaces consumer goods and seeks to replace endangered elements with earth abundant ones.

Reduce

It seems abundantly clear that, until new helium fields are found or efficient MRI scanners are produced that do not need liquid helium we should never use helium in party balloons and we should insist that the 95% helium is purified and recycled. Just in case you are unconvinced, think about the plastic that makes up the balloon itself. It floats away and contaminates the environment. It can be eaten by birds and sea creatures causing premature death from plastic pollution. Even so-called biodegradable balloons take up to a year to degrade—the damage is done by then. This is partly why Gibraltar, where tens of thousands of helium balloons were released every year on their national day, has banned them. In addition, Network Rail in the UK reports that in 2018 there were 619 incidents, many of them dangerous, in which helium balloons interrupted the rail service. Often the fly-away clusters of balloons get caught in gantries and overhead cables. **Can we really justify throwing away this precious resource in frivolous party balloons?**

What about phones? Most people are persuaded to change their phone every 2 to 3 years as part of their contract. Is this really necessary? Most people never use the new features of new phones and most phones are in good condition when they are exchanged. Did you know that once you are eligible for an “upgrade” you are also eligible for a “SIM only contract”? This is much cheaper than the one you were on so why not save money and elements rather than having a new phone? **Can we really justify changing our phones every two years when precious resources in them are being used up? Think about this for all your electronic gadgetry, car, consumer goods etc. You could make a huge difference to life on earth.**

Repair

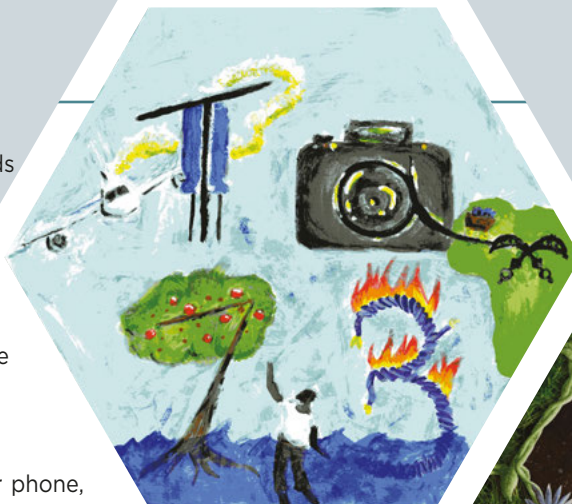
Sometimes the battery or screen on your phone may get weak or broken, the pump on your washing machine may break, you may need a new catch on your dishwasher and you will be advised that you need a whole new device. You almost certainly don't! A simple repair will be much less costly and more friendly to the environment. At present many mobile phone manufacturers make repairs very difficult by using special screws and extra strong glues. They should not be allowed to do this, at least until they tackle recycling,

and all consumer goods including phones should be made modular so that repairs are easy. It is sad that Google withdrew their modular phone before it even came to the market.

Recycle

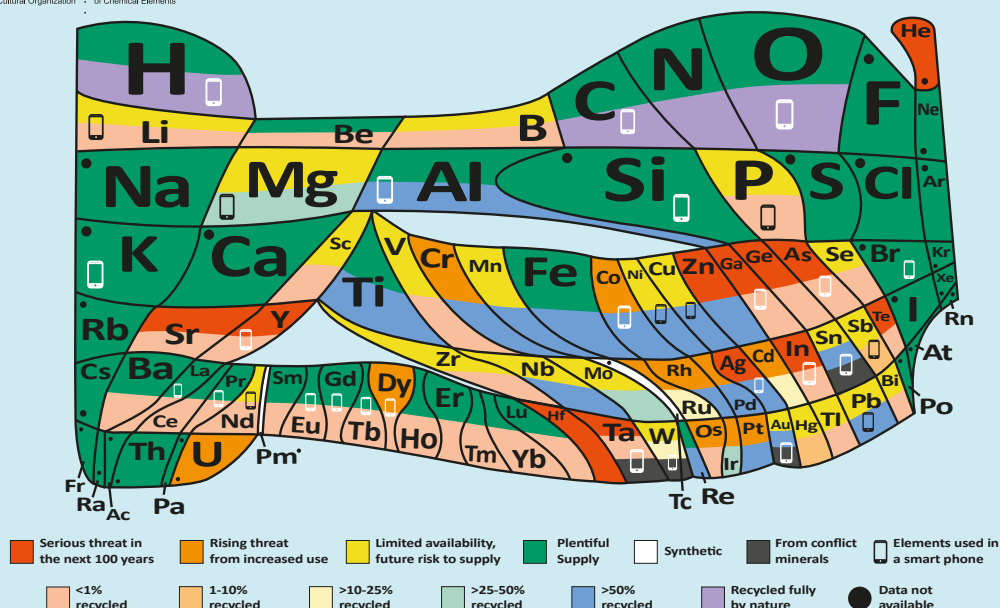
Even if you keep your phone, car, washing machine, etc for longer and repair it when it breaks down, eventually the time will come when it needs to be replaced. That is the time for recycling. Some items are already properly recycled. Look at the EuChemS Periodic Table again. Elements such as rhodium and platinum are in short supply but every car has some of each in its catalytic converter, which cleans up the exhaust emissions; yet these elements are not coloured red. This is because the elements in catalytic converters are recycled and indeed more than 50% of Rh and Pt in their myriad of uses are recycled (Figure 3) [8]. Why can't we do that with elements in electronic goods like phones and computers? We need to develop effective ways of recycling all the elements in mobile phones and

other electronic goods ethically. Some small companies do this already but we need to expand capacity dramatically. Then, **please do not keep your old phone in a drawer—recycle it ethically**, or give it to your granny, dad, or daughter until it is ready for recycling. This is **Reuse**, which is also part of the circular economy. A summary of the recycling of metals appears in Figure 3.



The 90 natural elements that make up everything

How much is there? Is that enough? What are we recycling?



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EuChemS
European Chemical Society

Figure 3. Modification of the EuChemS Periodic Table to include the extent to which element are recycled. Recycling data from https://www.resourcepanel.org/sites/default/files/documents/document/media/e-book_metals_report2_recycling_130920.pdf

Inspired by WF Sheehan's 'A Periodic Table with Emphasis' published in Chemistry, 1976, 49, 17-18'



Replace

Here, I do not mean replace your phone. What we need to do, in addition to all the things described above, is to find materials that do the same job as the ones we use currently but only contain earth abundant elements. Take the conducting film on touch screens: the film has to be transparent, colourless, conduct electricity and stick to glass. Indium tin oxide does all of these things exceptionally well, but it contains indium, whose supply is threatened, and tin, which can come from conflict zones. A huge amount of research is going on to find replacements. Graphene, made only from carbon, and calcium molybdate are amongst the front runners, but their performance does not match that of indium tin oxide yet. We need to ensure that this kind of research is fully supported.

Conclusion

The new EuChemS Periodic Table highlights the vulnerability of several elements to dispersion, but it also provides a clarion call for us to change our ways. If we adopt the circular economy consisting of reusing, reducing, repairing, recycling and attempting to replace vulnerable materials with less vulnerable ones, we shall be able to continue to enjoy our wonderful, diverse world for generations to come and reduce its pollution.

More information is available in support notes at <http://bit.ly/euchems-pt>, where the EuChemS Periodic Table can be downloaded in more than 30 languages. You can also download the video game *Elemental Escapades, A Periodic Table Adventure*. 



Acknowledgements

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Elements of Flair and Fashion

by Marielle Agbahoungbata

Let us start with a simple question: what allows you to read this article? Your eyes, the light? Whatever your answer is, you are right. But now, please, keep your eyes open and the light on, and imagine that this text is written exactly in the same colour as the paper. Would you be able to read?

Colour, of course, plays an important role. Colour has always had a huge impact on our lives. It has generated many human tragedies in history such as slavery and colonialism, and yet saves the world from disasters every day through traffic lights and other vital means of communication. From the clothes we wear, to the food we eat, and the cars we drive, colour is an essential feature which guides our choices, reveals our emotions and structures our life. Gaining more insight into colour matters is an important issue that goes far beyond simple curiosity. What does colour mean?

This question brings us back to our first question. Indeed, whatever the quality of your eyes and the colors used for printing this text, you cannot read it without light. As an electromagnetic radiation, light has frequency. The frequency of light that our eyes can detect is called colour. Color is the characteristic of human visual perception described with names such as red, orange, yellow, green, blue, purple, or pink. When light shines on an object, some frequencies (colours) are reflected whereas others are absorbed. The substance responsible for this phenomenon within objects is called colorant. The absorption of electromagnetic radiation in the ultra violet (UV) and visible regions by these coloring substances induces electronic excitation and a shift to higher energy levels. Next, the excited electron relaxes to its ground state by emitting a quantum of light called a photon. Our eyes detect this light as a color. For instance, we can see a lipstick is red because it absorbs all frequencies in the visible light except the one that corresponds to red color. White paper reflects all frequencies in the visible light (no absorption) while black ink absorbs all of them (no reflection). A covalently unsaturated group responsible for absorption in the UV or visible region is known as a chromophore ($C=C$, $C\equiv C$, $C=O$, $C\equiv N$, $N=N$, NO_2). Colorants are understood to include both pigments and dyes. The key distinction between them is that dyes are soluble in water and/or an organic solvent, while pigments are insoluble in both types of liquid media. The majority of natural colorants are derived from plants (roots, berries, bark, leaves, wood, fungi and lichens), minerals (oxide, silicate, carbonate, etc.)

and animals (snails, mollusk, insect). However, a significant number of colorants were artificially synthesized as soon as color became important in our need to improve our environment and clothing.

Indeed, ever since pre-historic times, humans were fascinated by the ability of coloring objects of their daily lives. From Ancient Egypt, a civilization of ancient North Africa that coalesced around 3100 BC, to now, the world has enjoyed a ground-breaking history as far as the use of dyes and pigments is concerned. Several different types of natural dye were used by Ancient Egyptians in the field of fashion [1]: *Archil* or *orchil*, a purplish blue dye obtained from lichen and known as “poor man’s purple.” Its chemical constituents are essentially carbon (C), hydrogen (H), oxygen (O) and nitrogen (N) in a quite complex structure. *Alkanet* or dyers’ bugloss (chemical constituents C, H, and O) is a perennial low growing herb (*Anchusa tinctoria*) with bright blue flowers. Its red dye was obtained from the



Lagos Fashion Week 2017, credit: <http://lagosfashionweek.ng/category/highlights/lfdw-2017/>

roots. *Madder dye* (composed of C, H and O) was usually obtained from common madder (*Rubia tinctorum*), an evergreen plant growing up to 1.5 m tall and having five yellow petals, producing blue to black berries. This dye is obtained from its long roots, and chalky soils produce the best quality. It was used to dye wool, cotton, silk and leather.

A dye from the animal kingdom, *Kermes dye* (C, H, and O), was obtained by boiling the bodies of female insects of the Kermes family (*Coccus ilicis*) until dry and then ground. It was applied to fibers with an alum mordant. It takes 150 000 insects to produce 1 kg of dye.

Indigo dye (C, H, O and N) is among the oldest dyes used for textiles. The oldest known fabric dyed indigo dates to 6 000 years ago, and was discovered in 2009 at Huaca Prieta, Peru. Many Asian countries, such as India, Japan, and Southeast Asian nations have used indigo as a dye (particularly silk dye) for centuries. This dye was also known to ancient civilizations in Mesopotamia, Egypt, Britain, Mesoamerica, Peru, Iran, and Africa. A variety of plants have provided indigo throughout history, but most natural indigo was obtained from those in the genus *Indigofera*.

Another dye, *Henna* (C, H, O) was prized in Egyptian and Greek mythology as a cosmetic. The Egyptians ground the leaves then pasted them on the skin in order to decorate fingers and toenails. It could be used to colour hair and by men to dye their beards, moustaches, and even the manes and tails of their horses. Henna is widely used still in most West African countries for the same needs.

Similarly, the Egyptians were very familiar with a number of mineral pigments obtained from natural ores as well as oxides [1]: the *orpiment* pigment is lemon yellow in colour, its formula is As_2S_3 . A small bag containing the pigment was found in Tutankhamun's tomb (1325 BC), apparently as a cosmetic. *Realgar* pigment has been found at several Egyptian sites, including a 14th century BC tomb, where it appears to have been used as a cosmetic. It can be a reddish yellow to orange with formula often depicted as AsS , but better represented as As_4S_4 which can exist in different crystalline structures.

Vermilion is a pigment obtained from the mineral cinnabar and designated HgS . This pigment can be obtained by heating sulfur and mercury above 580 °C, when the vermillion sublimes, condenses and is collected as bright red crystals, giving an intense shade. *Malachite green* is an organic compound that is used as a dye for materials such as silk, leather, and paper. The Egyptians used it as a cosmetic as far back as the Badarian period (5000 BC). Formally, *malachite green*

refers to the chloride salt $[\text{C}_6\text{H}_5\text{C}(\text{C}_6\text{H}_4\text{N}(\text{CH}_3)_2)_2]\text{Cl}$, and it was also found in Tutankhamun's tomb (1325 BC). *Azurite* has the same structure as green malachite. Although it does not fade, it slowly changes color to green malachite.

The Egyptian blue pigment is considered to be the oldest synthetic pigment. It is made by heating together silica, malachite $\text{Cu}_2\text{CO}_3(\text{OH})_2$ (not to be confused with malachite green), CaCO_3 and soda or potash at 900 °C. The resulting product has a composition $\text{CaO}\cdot\text{CuO}\cdot 4\text{SiO}_2$. Apart from all these famous dyes and pigments, there are medieval dyes and pigments such as *Brazil wood* from Asia, notably Sri Lanka and the East Indies, *logwood* from Central America, *Cochineal* from Aztecs, *Lapis lazuli* from Afghanistan but used for the gold mask found in Tutankhamun's tomb, *Indian yellow* from India, *Prussian blue*, etc.

If colour has had a huge impact on fashion in the past, contemporary fashion is still governed by colour. From hair to toes, color plays an important role. Hair colouring is the practice of changing hair color in order to cover gray or white hair, to change to a colour regarded as more fashionable or desirable, or to restore the original hair colour after it has been discoloured by hairdressing processes or sun bleaching. Depending on the goal (permanent, semi-permanent, demi-permanent or temporary hair coloring), several dyes are used. Their main components are ammonia, ethanolamine, sodium carbonate, hydrogen peroxide, and paraphenylenediamine. Several dyes and pigments (ultramarine blue, iron oxide, titanium dioxide, carmine, eosin, and others) are also used to produce lipsticks, skin-care creams, eye and facial makeup.

As far as our body is concerned, the possibility of using colour to control food consumption is attractive for weight-loss programs and even for the treatments of eating disorders [2]. There is an interesting study that shows that serving dishes on red plates could reduce food consumption. Indeed, subtle red color cues significantly reduced the consumption of soft drinks and salty snacks compared to blue or white color cues.

Decidedly, color plays a significant role in the field of fashion. When talking about clothes, it is estimated that over 10 000 different dyes and pigments are used industrially and over 7×10^5 tons of synthetic dyes are annually produced worldwide. Selection of the appropriate dye is important because any given dye is not suitable on every type of fiber. Furthermore, resistance to washing, rubbing and light differ among dyes. The choice of dye depends on the objective in dyeing and which material is to be dyed. Azo dyes make up over half the dyes classified in the Color Index, covering

the whole spectrum, but mainly yellow, orange and red dyestuffs. They are characterized by one or more azo groups ($-N=N-$). Acid dyes are used mainly for the coloration of wool and nylon and, to a lesser extent, silk and acrylics whereas basic dyes were originally used mainly for silk, although nowadays they are used for acrylic fibers, where they provide good fastness. Direct dyes were used on cellulose and disperse dyes were developed for cellulose acetate but now their main application is for polyester. Reactive dyes are known to be able to achieve the whole gamut of colors. Others dyes such as malachite green, mauveine ($C_{26}H_{23}N_4^+X^-$), Congo red ($C_{32}H_{22}N_6Na_2O_6S_2$) are widely used in the dyestuff industry.

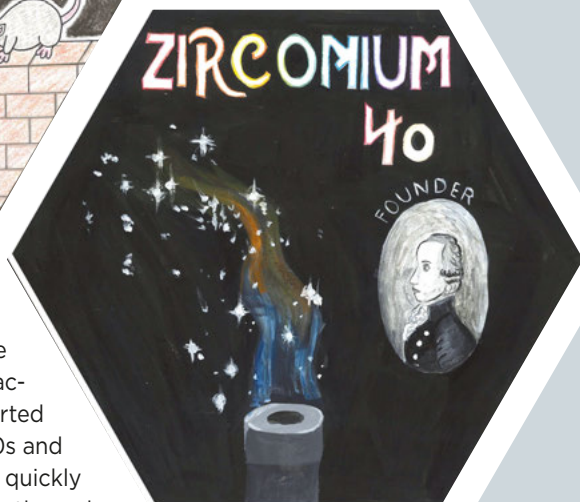
The development of fashion in Africa has impacted the development of some traditional dyes workshops. Especially in West Africa (Mali, Guinee, Senegal, Benin,

and Cote d'Ivoire) textile dyeing activities started in the 1960s and has been quickly developed through the 1990s into today.

For instance, in Benin, the approximate amount of dyes used per day in a small workshop can reach 50 kg [3].



Images Credits, see page 3.



Group of periodic table	Examples of elements in colorant	Colorant	Colour	Main applications
1	Sodium (Na)	Azo dyes	Red, blue	Textile
2	Magnesium (Mg) Calcium (Ca)	Magnesium carbonate Egyptian blue	White Blue	Cosmetics Art
3	-	-	-	-
4	Titanium (Ti) Zirconium (Zr)	Titanium dioxide Zirconium oxide	White White	Cosmetics Jewellery
5	-	-	-	-
6	Chromium (Cr)	Azo dyes	Violet	Textile
7	-	-	-	-
8	Iron (Fe)	Indian red	Red	-
9	Cobalt (Co)	Cobalt blue	Blue	Coating
10	Nickel (Ni)	Nickel salts	Several	Dye mordant
11	Copper (Cu)	Azo dyes	Blue	Cosmetics
12	Zinc (Zn)	Zinc white	White	Art
13	Aluminium (Al)	Carmin	Red	Textile
14	Carbon (C)	Organic dyes	Whole spectrum	Textile, cosmetics
15	Nitrogen (N)	Azo dyes	Whole spectrum	Textile, cosmetics
16	Oxygen (O) Sulfur (S)	Azo dyes Azo dyes	Whole spectrum	Textile, cosmetics
17	Chlorine (Cl)	Azo dyes	Green, red	Textile
18	-	-	-	-



These dyes/pigments are powdered in different colors: green, blue, red, yellow, brown, black, orange, pink, purple, and more, and contain, in addition to organics, some metallic elements such as Cr, Pb, Zn, Cd, and Hg.

However, the dyeing activity is likely going to be gradually industrialized in West Africa since fashion has become one of the biggest sectors within the continent. The famous Lagos Fashion Week (LFWNG) is an excellent illustration. It is an annual multi-day event founded in 2011 by Omoyemi Akerele, a Nigerian fashion designer. LFWNG is a fashion platform that drives the Nigerian and ultimately, the African fashion industry; by bringing together buyers, consumers and the media to view the current collections of designers in the fashion capital of Lagos, Nigeria. The fashion and exhibition event includes: Runway shows featuring new season collections from the best talents in the fashion industry; exhibitions featuring fashion products and accessories, textiles, design elements, photography; and art installations workshops and master classes facilitating knowledge transfer, information exchange, and networking opportunities across the board. The next Lagos Fashion Week will be held from 23-26 October 2019 in Lagos, Nigeria.

Like dyes and pigments, there are also others important ingredients in use for thousands of years in the field of flair and fashion: gold and gemstones. Gold (Au) is a chemical element, the most malleable of all metals, with a slightly reddish-yellow color used as jewelry since the ancient Egyptians. Nowadays, the consumption of gold produced in the world is about 50% in jewelry. As opposed to gold, a gemstone is



a piece of mineral crystal, a solid chemical compound that occurs naturally in pure form, used to make jewelry or other adornments in its cut and polished form. Since the beginning of time, people have been fascinated by the beauty and purity of gemstones such as diamond (a solid form of element carbon), ruby (aluminum oxide), emerald

($\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$), sapphire ($\alpha\text{-Al}_2\text{O}_3$), and others. Their exceptional beauty is generally due to their color. As previously explained, a gemstone's color comes from its interaction with light. However, a gemstone which is mostly the same can exhibit different colors. For example, ruby and sapphire have the same primary chemical composition (both are aluminum oxide) but exhibit different colors because of impurities: *i.e.* an atom in the primary structure of the mineral is replaced by a completely different atom, sometimes as few as one in a million. Another example is beryl. It is colorless in its pure mineral form but becomes emerald with chromium impurities. If manganese is added instead of chromium, beryl becomes pink morganite, and with iron aquamarine.

As you could notice, the history of color in the field of fashion and flair has been with us for millennia. As we review the periodic table of elements, we see that almost all the eighteen groups of the table have been mentioned by talking about elements of color. The table on the previous page shows that at least one element in most groups is used in the field of fashion. Moreover, most periodic tables themselves use color. Some use colors to distinguish metals, non-metals, metal-like, noble gasses, and rare-earth elements from each other. The history between fashion and the elements of the periodic table is surprisingly amazing. Let's keep an eye on them. 🕶️

Acknowledgements

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Marielle Yasmine AGBAHOUNGBATA <hounmar@gmail.com> is the Coordinator of X-TechLab, a platform dedicated to X-Ray Techniques in Africa. She holds a PhD degree in inorganic chemistry from University of Abomey-Calavi in Benin. Her research focus on the development of titanium dioxide based photocatalyst materials for wastewater purification. In 2019, celebrating IYPT and the 100th anniversary of IUPAC, she was awarded element 12, magnesium, on the IUPAC100 Periodic Table of Younger Chemists, <https://iupac.org/100/pt-of-chemist/#marielle-yasmine-agbahoungbata>.

IYPT2019 CLOSING CEREMONY

5 December, Tokyo Prince Hotel



<https://iypt.jp/en.html>

Elements of Heroism

by *Suze Kundu*

In today's periodic table, 118 elements stand side by side, neatly arranged in rows and columns, mapping out their relative size, proudly sharing their family's traits, and showcasing their relative reactivity and predicted behaviour in different situations. Back in 1869 when Dmitri Mendeleev devised the arrangement of elements we use to this day, there were notable gaps left for elements that had not yet been discovered. As the arrangement of the elements was based on a range of physical and chemical properties, it was easy to predict some of the properties of the missing elements. It was in these gaps that both scientists and artists alike dared to dream about elemental discoveries with both predicted and unpredicted properties. Comic book and science fiction writers in particular had fun postulating some of the possible elements that would give their superheroes the characteristics they required to carry out their tasks. They created fictional elements in place of some of the as yet undiscovered elements, many of which now share properties with elements that exist today.

Fictional elements feature in a range of superhero worlds. Invariably, these materials possess materials characteristics that solve a particular problem or meet a specific need. Many of these made-up elements could fit logically into the periodic table, resembling an existing element. However, let's start with an element that currently has no place on today's periodic table, owing to the definition of 'element' we use; neutronium. The number of protons in a single atom from a collection of identical atoms defines an element. For example, if the atoms of a pure element happen to all contain six protons, that atom is defined as a carbon atom, regardless of how many neutrons and electrons it may possess; variation in the number of neutrons gives rise to a range of isotopes with different relative atomic weights and the potential for instability and radioactive decay in those with more neutrons than protons in the nucleus.

If an atom is made solely of neutrons, it does not fit this definition of an element, as its atomic number is zero. Such an element would occupy position zero on the periodic table with one fewer proton than hydrogen, the first element in the periodic table. Where would this element go? Does it exist purely as a collection of single particles? Can it be referred to it as an atom if it has no protons, no nucleus, and no electrons orbiting it? Can neutronium particles clump together in a stable form? Do differently-sized clusters behave

the same? Can we still call all of these materials neutronium, or do they require more specific names? Without electrons or any sort of electrical charge generating an attractive force, how can these particles bind together? Is there a maximum size of clump? Despite the several tricky questions that arise when we begin to talk about this particular fictional element, neutronium has made several appearances in many episodes of *Star Trek*.

Neutronium doesn't waste any space with near-empty orbitals, unlike like a hydrogen atom. Given this, it is highly compressible, therefore it is no surprise that this fictional element is extremely dense. Is neutronium strong? In *Star Trek*, yes, however most materials utilise weak intermolecular, or indeed interatomic, forces to bind individual atoms together, if not a covalent bond where electrons are shared between atoms. If there are no attractive forces between atoms, and no electrons available for bonding, the particles cannot bind to one another, nor can they repel each another. As such, it is unlikely that this form of neutronium could withstand large impact forces. It is however so dense that it can distort time and space.

This form of neutronium has been hypothesised to be a real-life material found within small, dense



Widmanstätten pattern in a meteorite at the American Museum of Natural History (credit: Dr Suze Kundu)

neutron stars. If we define neutronium as a collection of single neutron particles, clusters of neutron particles give rise to dineutronium, trineutronium, tetraneutronium, pentaneutronium, and so on, each named for the number of neutron particles that have bound together. Whether we can call them isotopes of the same material depends on whether we can indeed say that neutronium is an element with atomic number zero. This hypothetical clustering is only possible within neutron stars, where the gravitational force is strong enough for particles to bind together for short amounts of time.

This description of neutronium does not match the material properties of the neutronium in *Star Trek*. Given the fact that the material is used as a strong armour for ships and machinery, it must be a material whose atoms are tightly bound together. Without this, it simply would not be able to withstand an attack. While its density may have contributed to its name, the material seems to be almost indestructible in the low gravity conditions of space. Under such low gravitational force, hypothesised neutronium would immediately dissipate away as the particles would resist remaining in their highly compressed state. It may be possible to artificially create a large gravitational force, but if it were strong enough to hold neutronium particles together, it would also be destructive to all other materials, not to mention creatures on the ship. It is therefore thought that the neutronium in *Star Trek* more closely resembles a much heavier element on the periodic table, such as the transuranic elements, or even an alloy like stainless steel with high density and tensile strength. Similarly, the so-called deuteronium employed as a fuel in Cardassian vessels would make a terribly energy-inefficient choice if the fuel were as dense as the similarly named dineutronium described here.

While there is no place for neutronium in the periodic table as we know it, creators of some fictional elements have been so bold as to occupy the place of existing elements on the table. If we once again look at *Star Trek*, the source of a huge amount of research inspiration, we find an element called dilithium with atomic number 87, which in our world corresponds to the element francium. Dilithium is somewhat of a misnomer, as it is not simply two lithium atoms bonded together, but an element all of its own. Dilithium has the ability

to keep matter and antimatter separate within what is known as the warp core, a piece of kit a little like a reactor that

generates enough useful energy to allow the *Star Trek* crew to navigate their ship through space at a speed faster than light (in ways that are, thankfully for us, better confined to physics journals). By controlling the amount of interaction between matter and antimatter, these two substances that would otherwise violently explode on contact have the energy of such a reaction liberated in a controlled manner through sustained low-level annihilation. This is what powers the huge space ships seen whizzing through space in the show.

Not content with having invented just one element, another of the many other fictional elements in *Star Trek* is trillithium, which is a by-product of these propulsion systems. Trillithium is able to inhibit nuclear reactions, such as this fusion of matter and antimatter in the warp core, thus working in beautiful synergy with dilithium as a handy engineering control for maximum safety onboard the ship. Though such materials have not yet been discovered, they continue to provide inspiration for technological advances in nuclear power in the world today.

Another element found within the realm of superheroes is kryptonite. This element exists in a range of shades, though the most familiar colour is green. Kryptonite usually glows, and its radiation is harmful to Superman's species, though it does not have as much of an impact on humans. While this element is not found on the periodic table, we have a similarly named noble gas element in krypton, which shares the same name as the alien planet that kryptonite originated from. Superman famously had some sort of allergy to this



Images Credits, see page 3.



material. As the meteorite that brought kryptonite in the universe was the only source, Superman was able to trace the mineral back to his home planet and discover his own origin story. In a similar way, there are certain areas in the world where terrains have such specific elemental compositions that samples can be analysed and traced back to their geographical origins.

Similarly, a number of real-life oddities on Earth are meteorites. The Earth's heavy bombardment from meteorites some 4 billion years ago gave rise to many 'alien' discoveries, such as the Widmanstätten patterns displayed in the Arthur Ross Hall of Meteorites at the American Museum of Natural History. Such crystal grain patterns had never been seen before. These strangely patterned rocks arrived here in the same way as kryptonite; hitchhiking inside a chunk of space rock.

We have two of those aforementioned neutron stars to thank for the presence of many precious metal elements on Earth. Most elements heavier than iron, and not synthetically produced, were formed when two neutron stars collided, throwing out enough energy for lighter atoms to fuse together to make heavier atoms of new elements. The Earth formed from many fragments of rock containing these elements, and these elements sank down into the Earth's crust owing to their relatively higher density, while lighter elements and compounds floated to the top to form the Earth's crust. However, we are still able to mine precious metals held in rocks on the surface of the Earth thanks to the continued influx of similar meteorites containing these elements that landed on Earth and settled into the Earth's crust, ready for us to mine them.

Having looked at elements that are comparable to existing real elements in name or property, let's focus on a mysterious element that possesses many desirable properties for its Middle Earth users; Mithril, which features in the Lord of the Rings trilogy of books. With a range of amazing chemical and physical properties that you would be hard-pressed to find in any one single element in the real world, mithril has a range of applications, from decoration to armour. With such versatility and reliability, this element was revered and hunted by many in Middle Earth. Mithril is a shiny, silvery metal, which is said to gleam and glow in moonlight, and can be shaped easily to make anything from an ornate door frame to a crown, and from a stone-set ring like Narya, one of the three rings of the elves of Middle Earth, to several rings connected as chain mail, like the chainmail shirt that Frodo sports under his regular elven clothes.

It is rare for any metal to retain a shiny surface as, over time, oxygen in the air oxidises the metal, forming a thin and protective oxide layer on the surface.

This reduces the reactivity of the metal, and can also change its properties if, for example, the oxide is less shiny, is brittle, or does not conduct heat or electricity in the same way as the metal would. As mithril remains so shiny, it either does not oxidise, or mithril oxide is also very shiny and possesses many other properties of the elemental metal itself.

For mithril to be used in chain mail, it must be strong and tough to be able to protect the wearer in combat, malleable enough for rings to be shaped or have a low enough boiling point for rings to be cast from it, and light enough to wear without impediment to stealth and swiftness in battle. If we were to try and recreate something as strong and light on Earth, we could look to titanium, but its similarities stop at its low density and high strength, as it is inflexible and not malleable. The closest material is an alloy of stainless steel with a nanocarbon content high enough to make it both strong and light, but that can also be cast into tiny rings ready to be interlinked. The biggest challenge would be keeping the material shiny, as most materials tarnish over time and with use.

As researchers continue to experiment with metals that are both light and strong for use in cars and aeroplanes to increase their energy efficiency and reduce pollution, mithril has inspired another exciting area of research; wearable tech. In 2003 the MIThril group at the MIT Media Lab were working on human-computer interactions for technology worn by people for health and communications [1]. One such piece of technology was a wearable helmet that delivered real-time diagnostic information to the wearer, while also protecting them and allowing them to interact with the various components of wearable tech on their bodies [2]. A helmet with an onboard computer immediately reminds me of Iron Man, and a range of fictional elements which reside in the Marvel Cinematic Universe, or MCU.

In the MCU we see many leaps of technological faith, but some of it could be attributed to cutting-edge science being carried out today. For example, in the MCU, Captain America's iconic shield is made of pure vibranium. Black Panther, who hails from Wakanda where the meteorite containing vibranium fell, has a thin and armoured suit made of fabric woven with vibranium. According to the 2018 film 'Black Panther,' vibranium is "the strongest substance in the universe." It must also be very light if it is carried around as a shield, thrown at enemies, and worn as an agile smart-suit. Though Captain America's shield develops some bumps and scratches from Black Panther's claws it was, at least until recently, seen as being virtually indestructible. That was of course until Infinity

War and EndGame, the MCU's two-part culmination of a series of movies leading up to the moment they need to restore half the world's population after the evil Thanos indiscriminately turned them to dust.

Thanos was able to break Captain America's shield, suggesting that his gauntlet is either made of vibranium, or a material even stronger than vibranium. We also see Tony Stark's Iron Man help defeat Thanos by removing the Infinity Stones from his gauntlet. How is that possible? Fan theories suggest that they could simply have migrated to Tony's gauntlet if the two were made of a similar nanomaterial. Given that Tony Stark's father Howard first made a shield for Captain America, and that Tony presented Captain America with a new shield in EndGame, it is not difficult to believe that there may have been enough scrap vibranium lying around for him to have fashioned some wearable tech out of it.

The creator of the shield, Howard Stark, tells Captain America that vibranium is a third as dense as steel alloy. Presumably it can also be spun into fibres that can be woven into a mesh if it used in Black Panther's armoured suit. Information in the MCU also tells us that this suit is capable of withstanding the impact of most weapons. Comparing this strength and density to a real-life element, titanium would once again be close [3]. However, even though it is robust and resistant to scratching and denting, it would simply be too heavy with around two thirds of the density of steel.

Vibranium is able to absorb the energy of an impact, store it and release it later, effectively behaving like a capacitor. It is also able to spread a large amount of energy across the shield or the suit, rather than through it, so any impact from a weapon would be dissipated across the body rather than towards and through it. With this many wonder properties, it is hard to believe that there is an Earth-bound element that could possibly match these properties. Beautifully, it is the element that connects every element in the periodic table that also provides a potential connection to our fictional world.

I mentioned carbon at the start of this essay. Elemental carbon is able to form a range of polymorphs, from diamond to graphite, and a range of intricate cage-like



balls and straw-like tubes. If we were to isolate one of these monoatomic layers of carbon we have graphene, which would be a good substitute for vibranium, which can also behave like a capacitor, and also has low density and high tensile strength.

Given that this is a celebration of the periodic table of elements, there has been no mention of alloys, however the fictional alloys and composites featured in superhero worlds have some of the most fascinating and extreme physical and chemical properties, and deserve their own future article when we celebrate such materials. Fictional elements were created by people who dared to look at existing research and think outside the box to solve their particular problem. On both an atomic scale as well as a professional scale, the best chemistry happens when elements work together. New compounds and novel composites can give rise to new developments and applications, while working as a team on different aspects of the same problem can lead to faster development of real-life solutions to the global challenges that we face. For elements, as well as for chemists, there is only one way to sum this up; Avengers, Assemble. 🌐

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2. <https://tmt.media.mit.edu/impact/mithril.html>
3. *Nature Chemistry*, 11(1), 13-16, 2019, <https://doi.org/10.1038/s41557-018-0194-5>

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Md, mendelevium, 101—Westwood Community High School—Fort McMurray, Alberta, Canada—Teacher: Lori Simpson—Artist: Farah Sadek

C, carbon, 6—ATEMS (Academy of Technology, Engineering, Math, and Science) and ACT2 (Associated Chemistry Teachers of Texas)—Abilene, Texas, USA Teacher: Julee Isenhower—Artist: Layla Ingram-Alger

H, hydrogen, 1—Exploits Valley Intermediate Grand Falls - Windsor, Newfoundland, Canada—Teacher: Krista Simms—Artists: Devyn Hogg, Maya Fifield, Emily Hayden, Claire Loder, Cora Hogg

Pa, protactinium, 91—Plano West Senior High School—Plano, Texas, USA—Teacher: Nicole Lyssy—Artist: Emily Ren

He, helium, 2—Senator O'Connor College School—North York, Ontario, Canada—Teacher: Alicja Koprianiuk—Artist: Jakub Brol

Si, silicon, 14—St. John's Kilmarnock School—Breslau, Ontario, Canada—Teacher: Sarah Regli—Artist: Max Dai

F, fluorine, 9—Texas A&M University San Antonio—San Antonio, Texas, USA—Teacher: Dr. G. Robert Shelton—Artist: Kiarah Craft

Ba, barium, 56—Eastview Secondary School—Barrie, Ontario, Canada—Teacher: Kristen Roth—Artist: Sydney Barber

U, uranium, 92—Heritage High School, Frisco ISD—Frisco, Texas, USA—Teacher: Jo L. King—Artist: Brigitte Kenna

Np, neptunium, 93—Victoria Shanghai Academy—Hong Kong, Hong Kong—Teacher: Isabella Liu—Artists: Jane Chan, Cherilynne Chau, Sammie Srirotjariya, Kaitlyn Chan, Charmaine Wan, Alicia Yu

Mc, moscovium, 115—School #192—Moscow, Russian Federation—Teacher: Leonid V. Romashov—Artist: Ekaterina Belichenko

Fl, flerovium, 114—Stanwood High School—Stanwood, Washington, USA—Teacher: Susan Hauenstein—Artist: Olivia Forcier-Capper

V, vanadium, 23—Kitchener-Waterloo Collegiate and Vocational School—Kitchener, Ontario, Canada—Teacher: Kate Rowlandson—Artist: Maggie Sweeney

Os, osmium, 76—Rockdale Magnet School for Science and Technology—Conyers, Georgia, USA—Teacher: Diana Kennen—Artist: Stephan Sellers

O, oxygen, 8—Preston High School—Cambridge, Ontario, Canada—Teacher: Kevin Donkers—Artist: Ella Woolcott (created for Science Teachers' Association of Ontario (STAO))

Ir, iridium, 77—Anchorage School District-Eagle River High School—Eagle River, Alaska, U.S.A.—Teacher: Matthew R. Prnka—Artist: Aidan Sutherland

Cu, copper, 29—Jacob Hespeler Secondary School—Cambridge, Ontario, Canada—Teacher: Yvonne Clifford—Artist: Madeleine Williams

Au, gold, 79—Spearfish High School—Spearfish, South Dakota, USA—Teacher: Jessica Zwaschka—Artist: Taya Lucas

Ag, silver, 47—Fundación Colegio Americano De Puebla—Puebla, Puebla, Mexico—Teacher: Priscilla Calva Ariza—Artists: David Albert Sarda Keen and Arantxa Marin Limon

N, nitrogen, 7—East Three Secondary School—Inuvik, Northwest Territories, Canada—Teacher: Denise Lipscombe—Artists: Fletcher Dares, Chloe Dalton, Corbin Dempster, Hannah Gordon-Rogers

Ta, tantalum, 73—Chilliwack Secondary School—Chilliwack, British Columbia, Canada—Teacher: Chris Reilly—Artists: Emma-Lee Riddolls and David Barg

In, indium, 49—Saskatchewan Indian Institute of Technologies—Regina, Saskatchewan, Canada—Teacher: Alex Hutchinson—Artist: ABE 10 Class

Tc, technetium, 43—Huron Heights Secondary School—Kitchener, Ontario, Canada—Teacher: Craig Matthews—Artists: Lakyn Hann, Stefan Djukic, and Ria Menon

Mg, magnesium, 12—John F. Ross Collegiate Vocational Institute—Guelph, Ontario, Canada—Teachers: Sue Bender and Michael Neerhoff—Artist: Riley Luke

Ga, gallium, 31—Hudsonville High School—Hudsonville, Michigan, USA—Teacher: Doug Ragan—Artist: Sophia Putman

Co, cobalt, 27—Malden High School—Malden, Massachusetts, USA—Teacher: Martin Berryman—Artist: Michelle Nie

As, arsenic, 33—Murdoch University—Murdoch, Western Australia, Australia—Teacher: Caitlin Sweeney—Artists: Caitlin Sweeney, Jamie Fletcher, Alice Barber, Rhianna Jones

Zr, zirconium, 40—Dubai College—Dubai, Dubai, United Arab Emirates—Teacher: Vanessa Holmes—Artist: Charmaine Kee

S, sulfur, 16—Lakota East High School—Liberty Township, Ohio, USA—Teacher: Elizabeth Gosky—Artist: Hailey Holtman

Sb, antimony, 51—Acheron College Grand Valley—Kitchener, Ontario, Canada—Teacher: Susan Van Acker—Artist: Amanda Dumont

At, astatine, 85—Quezon City Science High School—Quezon City, Quezon City, Philippines—Teacher: Richard Sagcal—Artist: Radioactive

Db, dubnium, 105—University of Toronto Schools—Toronto, Ontario, Canada—Teacher: Jennifer Howell—Artist: Janice Chung

Hs, hassium, 108—Saint Michael Catholic High School—Niagara Falls, Ontario, Canada—Teacher: Francesca Caruso-Leitch—Artist: Anna Ly

Rg, roentgenium, 111—Pui Kiu College—Hong Kong, China Teacher: TO Chin Nang—Artists: HAU Sze Chai, Scarlett

See entire gallery @ <https://uwaterloo.ca/chemistry/timeline-elements-image-gallery>

The Top Ten Emerging Technologies in Chemistry—Call for Proposals for 2020

IUPAC has released its call for proposals to identify the top ten emerging technologies in chemistry with the results to be announced in 2020.

This initiative began in 2018 in recognition of IUPAC's Centenary in 2019, and while it was created to kick off IUPAC's anniversary year in a very visible way, the end goal was to showcase the value of chemistry (and chemists!) and to inform the general public as to how the chemical sciences contribute to the well-being of society and the sustainability of Planet Earth. The finalists for 2019 were announced in April 2019 and detailed in the April/June 2019 issue of *Chemistry International* (CI).

The call for the 2020 proposals is now open. Anyone can submit one or more proposals—this call for proposals is open to the global science community as well as to the general public.

Call for proposals—deadline **31 October 2019**

<https://iupac.org/top-ten-emerging-technologies-call-2020/>

2020 IUPAC-Richter Prize in Medicinal Chemistry—Call for Nominations

The 2020 IUPAC-Richter Prize will be presented during the XXVI EFMC International Symposium on Medicinal Chemistry (6-10 September 2020) in Basel, Switzerland, where the recipient will also give a plenary lecture on the subject of their research.

The prize is to be awarded to an internationally recognized scientist, preferably a medicinal chemist, whose activities or published accounts have made an outstanding contribution to the practice of medicinal chemistry or to an outstanding example of new drug discovery.

Prize USD 10 000

The Prize has been established by a generous gift from the **Chemical Works of Gedeon Richter, Plc.** (Budapest, Hungary) to acknowledge the key role that medicinal chemistry plays toward improving human health.

Applicants should be received by NOMINATION only, with just one person needing to serve in that capacity, although a total of five (5) individuals should be listed as referees overall. The package must be submitted electronically and should contain a complete resume, a professional autobiography of not more than two pages, and a one-page summary of what

the individual considers to be their activities, accomplishments and/or publications that have had the most significant impact upon the field of Medicinal Chemistry. The material will be forwarded confidentially to an independent selection committee appointed by the IUPAC Subcommittee on Medicinal Chemistry and Drug Development.

For further information, please contact Prof. Janos Fischer, Member of the IUPAC Sub-committee on Drug Discovery and Drug Development, by email at <j.fischer@richter.hu>.

Nomination materials should be submitted by **15 December 2019**.

<https://iupac.org/2020-iupac-richter-prize-call-for-nominations/>

Awardees of the 2019 IUPAC-Zhejiang NHU International Award for Advancements in Green Chemistry

The first four recipients of the recently established IUPAC-Zhejiang NHU International Award for Advancements in Green Chemistry go to Mingxin Liu from McGill University, Montreal, Xiaofu Sun from the Chinese Academy of Sciences, Beijing, Julian West from Rice University, TX, and to Fabio Aricò from the Università Ca' Foscari, Venezia, Italy. The collaborative award in Green Chemistry has been established to encourage young and experienced chemists, and to emphasize the importance of advancements in Green



Presentation of the first awards at the IUPAC Congress in Paris on 12 July 2019; from left: Qifeng Zhou (IUPAC President), Pietro Tundo (ICGCSD Chair), Clement Sanchez (Congress Chair), Jean-Marie Lehn, Fabio Aricò, Xiaofu Sun, Haoran Li (NHU), and Jean-Pierre Vairon.

Chemistry and the value of sciences to human progress.

The awards were presented during the closing ceremony of the IUPAC Congress in Paris on Friday, 12 July 2019. The awardees also attended a special symposium titled “Chemistry Addressing the UN-17 Sustainable Development Goals,” organized by the IUPAC Interdivisional Committee on Green Chemistry for Sustainable Development (ICGCSD).

The winners have been invited to prepare a review article for publication in a coming issue of *Pure and Applied Chemistry*. The award will be presented every two years and the next call will be announced in 2020, in advance of the 2021 IUPAC Congress to be held in Montreal, Canada, 13-20 August 2021.

For reference and more details about the awards, including detailed bio of the awardees, see <https://iupac.org/iupac-zhejiang-nhu-international-award/>

In Memoriam: René Dybkaer

a personal memo shared by Brynn Hibbert

I first met René when the IUPAC General Assembly came to Brisbane Australia in 2001. IUPAC was not an organization I (then) knew much about, but I found myself confronted by Paul De Bièvre demanding that I join a task group on metrological traceability. At the time I would not have called myself a metrologist in chemistry (MiC) or in any other field. The great minds assembled for the project were Paul De Bièvre, René Dybkaer, Ales Fajgelj, and me. I had no idea that our task would take ten years (finally published as De Bièvre, P.; Dybkaer, R.; Fajgelj, A.; Hibbert, D. B.: Metrological traceability of measurement results in chemistry: Concepts and implementation (IUPAC Technical report) *Pure Appl. Chem.* 2011, 83, 1873-1935), and that during the time I would come to form strong friendships with my comrades in the “Gang of Four.” Paul is no longer with us and now René has left the stage.

René was tall, thin with a habit of pursing his lips while saying “Oh no, I don’t think that can be right” as he pointed out a logical flaw in an argument. He was invariably correct, and no one took offence, but



René Dybkaer (left) and Brynn Hibbert at the IUPAC Congress/GA in Torino in 2007.

always deferred to his clarity of thought. This led to a no-compromise approach. Whereas some of us would try and see the others point of view, René simply said what was correct and that was that. We met his splendid wife, and occasionally heard tell of his past. Had he really represented Denmark in the Olympic Games in the 1950s wielding a sword?

I served with René on the Joint Committee for Guides on Metrology (JCGM) Working Group 1, the committee that has the stewardship of the Guide to the Expression of Uncertainty in Measurement (GUM, JCGM 100:2008), and watched him as he created the Silver Book (G. Féraud, R. Dybkaer, and X. Fuentetaja: *Compendium of terminology and nomenclature of properties in clinical laboratory sciences: Recommendations 2016*; RSC Publishing: Cambridge, UK, 2017.) He was the master of the logical naming of quantities by dimension. So on page 146 of the Silver Book we find dimension $L^2MT^{-2}\theta^{-1}$ the “entire kelvin energy constant” which to you and me is simply the Boltzmann constant.

René was kind, and generous with his time and thoughts. He had an interest in science fiction and science fantasy and was happy to recommend titles, but above all René was an excellent teacher and companion. René passed away on April 29, 2019.

Human Health Risk Consideration on Nano-enabled Pesticides for Industry and Regulators

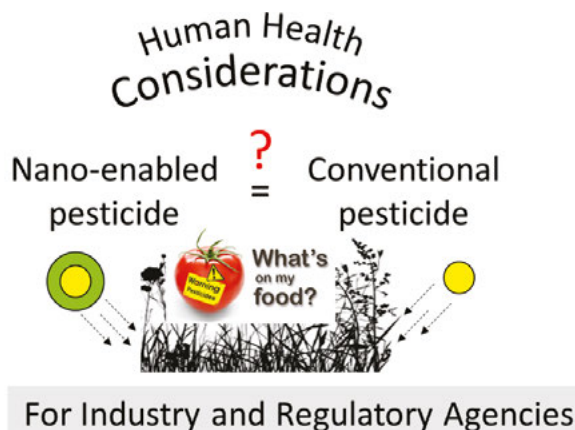
Nanotechnology is emerging as a highly attractive tool for the formulation and delivery of pesticide active ingredients (AIs) as well as enhancing and offering new AIs. There is a great deal of potential to decrease the amount of AI required as well as to produce alternative AI (Bioclay), but there are also concerns related to possible additional or alternate toxicity mechanisms for both the environment and human health. Several nano-enabled pesticides are in the pipeline and will need to be evaluated in the near future. Currently there is a lack of understanding among industry and regulators on:

1. The human health effects data that regulators will require to determine the risk profile of nano-enabled pesticides,
2. What methods/approaches are appropriate and acceptable to give industry confidence in obtaining and submitting the data required to satisfy the regulatory requirements?

To address the above, a IUPAC project was jointly developed by IUPAC Divisions VI and VII with COCI on Human Health Risk Consideration on Nano-enabled Pesticides to provide guidance to industry and regulators. The key objective of the project is to assist industry, contract research organizations and regulators in determining an acceptable and practical approach for identifying and generating the data relevant to human health risk assessment required for the registration of nano-enabled pesticides.

The project got an excellent start in June 2018 with a workshop in Boston that coincided with the Gordon Research Conference on Nanoscale Science and Engineering for Agriculture and Food Systems. The objective of the workshop was to identify questions that are specific to nano-enabled pesticides that must be addressed in addition to the questions normally asked for conventional pesticides.

The workshop brought together a range of expertise from regulators, industry, researchers, and academia. Regulatory agencies included the US Environment Protection Agency (EPA), US Food and Drug Administration (FDA), Health Canada, Australian Pesticides and Veterinary Medicines Authority (APVMA), each provided an overview of their approach for regulating nano-enabled pesticides/nanomaterials. Vive Crop Protection provided an overview of products likely to enter the market as well as an industry perspective on how these products are likely to be different than



For Industry and Regulatory Agencies

After Walker et al. 2017

conventional AIs. In breakout sessions, the group then discussed different routes of exposure (e.g. dermal, inhalation, ingestion) as well as stages of exposure (e.g. during mixing-loading, during application, workers, bystanders, residents). These were considered in relation to two case studies where (i) a nanocarrier system is used for a slow release of a pesticide AI (e.g. an insecticide molecule) and (ii) a pure AI nanoparticle is used for modifying the inherent chemical properties of the AI (e.g. to increase the "apparent solubility," retention on leaves or uptake in target organisms).

The workshop raised more questions than answers and identified several issues that need to be addressed while considering nano-enabled pesticides implications for human health, for example:

- Different jurisdictions have slightly different criteria for defining nano-enabled pesticides at the moment, similar to the current situation with defining nanomaterials by regulatory agencies. The boundaries are not yet clearly defined.
- The vast majority of nano-enabled pesticides are based on existing and already authorised AIs. The AI is the bioactive component, which is primarily tested for efficacy and potential undesirable effects, similarly to pharmaceuticals. In many cases, the other components of the formulations (inerts/excipients) also have to be considered.
- Pesticide AIs are always formulated, e.g. with surfactants, solvents, and/or inerts. Many formulations currently contain relatively large amounts of inerts, including non-nano forms of TiO_2 or silica. Can data related to existing excipients be used or should these inerts/excipients be treated differently in nanoformulations?
- The persistence of a nanocarrier may be assessed as part of the inert assessment on individual

components. However, the persistence of the fully formulated nanocarrier (with all ingredients, including the AI) may not be known. Does this raise issues?

- Considering the variability in excipients and formulations, what is the correct reference material? AI alone is currently used for toxicity studies, not the formulations.
- Nano AI may be stabilised with e.g. surfactants: Does the fact that they are, or are associated with, a nanoparticle, make them different from a toxicological perspective?
- For a nanocarrier composed of ingredients that are already considered safe: are there ways to design bridging studies and potentially use existing toxicity data? How should the dose be compared? What data is needed for bridging? How does one determine dose? What tests/end points are needed?

Considering the above and many more questions that were raised at the Boston workshop, a follow up workshop was organised to coincide with the IUPAC Centenary Celebrations and General Assembly in July 2019. Ultimately, as an outcome of this project, we hope to develop well-considered views on some of the above challenges.

Reference

1. Walker, G; R.S. Kookana; N.E. Smith; M. Kah et al. *Journal of Agricultural and Food Chemistry*, 66(26): 6480-6486, 2017. DOI: 10.1021/acs.jafc.7b02373.

For more information and comments, contact Task Group co-chairs Rai Kookana <Rai.Kookana@csiro.au> or Linda Johnston <Linda.Johnston@nrc-cnrc.gc.ca> www.iupac.org/project/2017-035-2-600

Trace elements analysis of environmental samples with X-rays

An increasing number of scientists from around the world are using X-ray based methods for the analysis of trace elements in environmental samples. X-ray analyses can be successfully performed both at synchrotron facilities and in modern laboratories with dedicated instrumentation.

Synchrotron X-ray methods can provide information on both the concentration and the speciation of trace constituents and is being utilized to unravel many chemical processes and transformations. Synchrotron generated X-rays can also help scientists to elucidate reactions occurring over different lengths and time scales, usually not possible with conventional



Roberto Terzano (IUPAC Division VI secretary and Project Task Group) and other Task Group Members (from left: David Paterson, Gerald Falkenberg and Ryan Tappero) presenting awards to the winners of the "IUPAC Division VI Best Poster Prize."

laboratory instruments. In recent years, new beamlines dedicated to environmental analyses have been commissioned at synchrotron facilities around the world and new methodologies have been developed for fast and sensitive trace elements analyses in environmental matrices. However, the number of requests for beamtime at synchrotrons has also increased exponentially making it increasingly difficult to obtain access to these large facilities.

Nevertheless, recent technological improvements in X-ray optics and detectors (many of which were pioneered at synchrotron facilities) have been incorporated into modern analytical instruments. These

Project Place

incremental advancements allow in-house analyses using techniques previously available exclusively at synchrotron storage rings. The use of these sophisticated X-ray instruments allows scientists to generate robust data without a synchrotron light source, also very useful to justify future synchrotron experiments.

The objective of IUPAC Project 2016-019-2-600 is to inform the environmental scientific community about recent developments in trace elements analysis of environmental samples with X-rays, available at synchrotron beamlines and with in-house laboratory instrumentation. Specifically, we are sharing the latest developments in X-ray technology (sources, optics, detectors) and sample preparation for the analysis of trace elements in environmental samples. Our goal is to promote the use of X-ray based methods among environmental scientists by enhancing the network of users, method developers, beamline scientists and instrument manufacturers.

To this purpose, a Special Symposium entitled "Trace elements analysis of environmental samples with X-rays" was organized during the 14th International Conference on Biogeochemistry of Trace Elements—ICOBTE 2017, which took place in Zurich, Switzerland. Thirty abstracts were received from 16 countries, with keynote lectures given by Antonio Lanzirotti from the University of Chicago (USA) and Laszlo Vincze from the University of Ghent (Belgium). The symposium,

co-sponsored by Bruker GmbH (Germany), was attended by about 100 participants. Three poster prizes were awarded by IUPAC Division VI to young participants: Barbara Lopata (Poland), Kathryn Spiers (Germany) and Antonio Caporale (Italy).

The symposia focused on how advances in instrumentation could be applied to understand the fate of trace elements in a variety of environmental problems. The morning session was devoted to synchrotron applications, while the afternoon session mainly focused on laboratory scale methodologies. During these sessions, recent improvements in X-ray analyses were presented. In particular, new developments in the fields of X-ray diffraction, X-ray fluorescence, and X-ray absorption were discussed. The latest developments using 2D and 3D applications were introduced, with a special emphasis on spatially resolved microscopic and sub-microscopic analyses of minor and trace elements in environmental matrices.

After the symposium, the task group prepared an IUPAC Technical Report entitled "Recent advances in analysis of trace elements in environmental samples by X-ray based techniques". The report has been published in *Pure and Applied Chemistry* (June 2019, 91(6), pp. 1029-1063; doi: 10.1515/pac-2018-0605.)

For more information and comments, contact Task Group chair Roberto Terzano <roberto.terzano@uniba.it> • www.iupac.org/project/2016-019-2-600



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IUPAC Periodic Table Challenge

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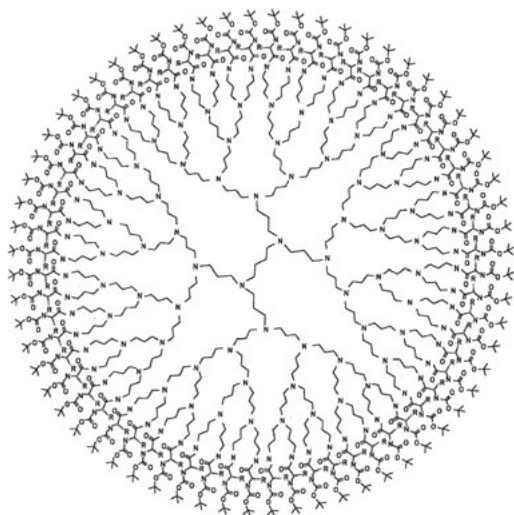
iupac.org/100/pt-challenge

Nomenclature and terminology for dendrimers with regular dendrons and for hyperbranched polymers (IUPAC Recommendations 2017)

Fradet, A., Chen, J., Hellwich, K., *et al.*

Pure and Applied Chemistry, 2019

Volume 91, Issue 3, pp. 523-561



The present document provides recommendations for (i) definitions of terms related to dendrimers with regular dendrons and to hyperbranched polymers, and (ii) nomenclature for naming these complex compounds on the basis of structure-based nomenclature for regular and irregular organic polymers, including adjustments required for specifying dendritic and hyperbranched macromolecular structures. The recommendations and the examples deal with organic-chemical structures only. Nevertheless, the general principles described in this document can similarly be applied to inorganic and to hybrid inorganic-organic dendrimers and hyperbranched macromolecules.

doi.org/10.1515/pac-2016-1217

List of keywords for polymer science (IUPAC Technical Report)

Slomkowski, S., Fellows, C., Hiorns, R., *et al.*

Pure and Applied Chemistry, 2019

Volume 91, Issue 6, pp. 997-1027

Internet searches of scientific literature return results based mainly on electronic engines, which work to identify relevant keywords. These keywords are supplied by the authors of publications. The selection of keywords that best describe the content of a

publication is therefore very important. Some publishers of journals related to polymer science provide a recommended list of keywords from which authors must select the most relevant terms. Wiley, for example does this. Some publishers, on the other hand, give authors license to provide their own keywords, while others provide a non-binding list of keywords, *i.e.* authors may use it or ignore it as they prefer. In addition to these variations, different authors place a different emphasis on the selection of keywords. Some take it as a serious exercise and strive to provide keywords that genuinely encapsulate the contents of their article, while others regard keywords as a nuisance and do not particularly care if they are a “low precision” guide to the content of their publication. Furthermore, as science is a dynamic discipline, newly discovered phenomena are constantly giving rise to new terms that may not be included in existing lists of keywords. All these factors introduce a degree of ambiguity which, in turn, makes searching the literature by keywords less accurate.

For these reasons it is worthwhile to collect the most salient terms from all areas of polymer science, *i.e.* polymer chemistry, polymer physics, polymer technology, and polymer properties, and then to assemble these terms into a representative list that may serve as an IUPAC-recommended list of keywords for polymer science. This is the aim of this paper. Ideally, all polymer-related journals would employ this list and would insist on authors selecting from it, except where terms are newly coined, in which event—if prudent—they would be added to the list, making it an evolving document. This would ultimately result in a streamlined search tool: faster, more comprehensive, and more accurate.

doi.org/10.1515/pac-2018-0917

Recent advances in analysis of trace elements in environmental samples by X-ray based techniques (IUPAC Technical Report)

Terzano, R., Denecke, M., Falkenberg, G., *et al.*

Pure and Applied Chemistry, 2019

Volume 91, Issue 6, pp. 1029-1063

Trace elements analysis is a fundamental challenge in environmental sciences. Scientists measure trace elements in environmental media in order to assess the quality and safety of ecosystems and to quantify the burden of anthropogenic pollution. Among the available analytical techniques, X-ray based methods are

particularly powerful, as they can quantify trace elements in situ. Chemical extraction is not required, as is the case for many other analytical techniques. In the last few years, the potential for X-ray techniques to be applied in the environmental sciences has dramatically increased due to developments in laboratory instruments and synchrotron radiation facilities with improved sensitivity and spatial resolution. In this report, we summarize the principles of the X-ray based analytical techniques most frequently employed to study trace elements in environmental samples. We report on the most recent developments in laboratory and synchrotron techniques, as well as advances in instrumentation, with a special attention on X-ray sources, detectors, and optics. Lastly, we inform readers on recent applications of X-ray based analysis to different environmental matrices, such as soil, sediments, waters, wastes, living organisms, geological samples, and atmospheric particulate, and we report examples of sample preparation.

doi.org/10.1515/pac-2018-0605

Guidelines for unequivocal structural identification of compounds with biological activity of significance in food chemistry (IUPAC Technical Report)

Molyneux, R., Beck, J., Colegate, S., *et al.*
Pure and Applied Chemistry, 2019
 Volume 91, Issue 8, pp. 1417-1437

Isolation of endogenous constituents of foods is generally performed in order to elucidate the biological activity of individual compounds and their role with respect to factors such as organoleptic qualities, health and nutritional benefits, plant protection against herbivores, pathogens and competition, and presence of toxic constituents. However, unless such compounds are unequivocally defined with respect to structure and purity, any biological activity data will be compromised. Procedures are therefore proposed for comprehensive elucidation of food-based organic structures using modern spectroscopic and spectrometric techniques. Also included are guidelines for the experimental details and types of data that should be reported in order for subsequent investigators to repeat and validate the work. Because food chemistry usually involves interdisciplinary collaboration, the purpose is to inform chemists and scientists from different fields, such as biological sciences, of common standards for

the type and quality of data to be presented in elucidating and reporting structures of biologically active food constituents. The guidelines are designed to be understandable to chemists and non-chemists alike. This will enable unambiguous identification of compounds and ensure that the biological activity is based on a secure structural chemistry foundation.

doi.org/10.1515/pac-2017-1204

Polymer Networks: Structure, Properties, and Function

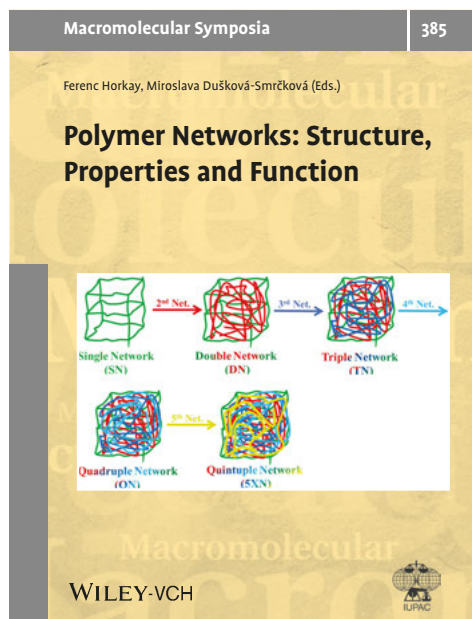
Macromolecular Symposia Volume 385, June 2019

This volume of *Macromolecular Symposia* is based on papers presented at the Polymer Networks 2018 Conference, 17-21 June, 2018, Prague, Czech Republic. The conference was organized together with the 82nd Prague Meeting on Macromolecules by the Institute of Macromolecular Chemistry, Czech Academy of Sciences. The symposium provided an international forum to discuss recent advances and future prospects in the field of polymer networks and gels.

The present collection of papers provides an overview of research advances in several areas of polymer networks and gels as well as their applications. The topics range from new theoretical and experimental concepts to groundbreaking research in the laboratory, such as development of novel and efficient biopolymer materials for medical applications (drug delivery, wound healing, etc.). The design and fabrication of novel polymer compositions and architectures aimed at enhanced functional properties are emphasized in several contributions.

Extract reproduced from the Preface by Ferenc Horkay and Miroslava Dušková-Smrčková.

doi.org/10.1002/masy.201970012



The Battle for a Sustainable Food Supply

Unsworth J., Nakagawa Y., Harris C., Kleter G. (2019) in Vaz Jr. S. (eds)

Sustainable Agrochemistry. Springer, Cham;

Since the time that *Homo sapiens* took up farming, a battle has been waged against pests and diseases which can cause significant losses in crop yield and threaten a sustainable food supply. Initially, early control techniques included religious practices or folk magic, hand removal of weeds and insects, and “chemical” techniques such as smokes, easily available minerals, oils, and plant extracts known to have pesticidal activity. But it was not until the early twentieth century that real progress was made when a large number of compounds became available for testing as pesticides due to the upsurge in organic chemistry. The period after the 1940s saw the introduction of

important families of chemicals, such as the phenoxy acid herbicides, the organochlorine insecticides and the dithiocarbamate fungicides. The introduction of new pesticides led to significant yield increases, but concern arose over their possible negative effects on human health and the environment. In time, resistance started to occur, making these pesticides less effective. This led agrochemical companies putting in place research looking for new modes of action and giving less toxic and more environmentally friendly products. These research programmes gave rise to new pesticide families, such as the sulfonylurea herbicides, the strobilurin fungicides and the neonicotinoid insecticide classes.

This work formed part of IUPAC project 2012-019-1-600.

https://doi.org/10.1007/978-3-030-17891-8_2

IUPAC Provisional Recommendations

Provisional Recommendations are preliminary drafts of IUPAC recommendations on terminology, nomenclature, and symbols, made widely available to allow interested parties to comment before the recommendations are finalized and published in IUPAC's journal *Pure and Applied Chemistry* (PAC). Full text is available online.

Glossary and tutorial of xenobiotic metabolism terms used during small molecule drug discovery and development

This project originated nearly 15 years ago with the intent to produce a glossary of drug metabolism terms having definitions especially applicable for use by practicing medicinal chemists. A first-draft version underwent extensive beta-testing that, fortuitously, engaged international audiences having a wide range of disciplines involved in drug discovery and development. It became clear that inclusion of information to enhance discussions among this mix of participants would be even more valuable. The glossary's present version retains a chemical structure theme, while expanding tutorial comments directed toward bridging various perspectives that may arise for a given term

during interdisciplinary communications. It is intended to be educational for early stage researchers, as well as being a useful resource for investigators at various levels who participate on today's highly multidisciplinary, collaborative drug discovery teams.

Comments by 31 December 2019.

Corresponding Author: Paul Erhardt <Paul.Erhardt@utoledo.edu>

<https://iupac.org/project/2000-009-1-700>

Terminology of electrochemical methods of analysis

Recommendations are given concerning the terminology of methods used in electroanalytical chemistry. Fundamental terms in electrochemistry are reproduced from previous PAC Recommendations, and new and updated material is added for terms in electroanalytical chemistry, classification of electrode systems, and electroanalytical techniques.

Comments by 30 November 2019.

Corresponding Author: D. Brynn Hibbert <b.hibbert@unsw.edu.au>

<https://iupac.org/project/2010-052-1-500>

Conference Call

Blood-Biomaterial Interactions

by Ilya Reviakine and Robert Latour

Interactions between biological systems and artificial materials have been intensely studied over the last several decades by an interdisciplinary group of scientists combining expertise in (surface) chemistry, physics, and biology [1 and refs. therein]. Nowhere are the limitations of our understanding of the underlying mechanisms more apparent than in the case of vascular implants that interact with blood and other surrounding tissues. Examples of such implants include stents, grafts, mechanical heart valves, and ventricular assist devices (VADs). Millions of stents are implanted in patients annually world-wide; hundreds of thousands of heart valves; thousands of VADs. All of them cause life-threatening thrombotic and inflammatory complications that are managed by clinicians pharmacologically through systemic administration of anticoagulation and/or antiplatelet therapies (ACT/APT) based on drugs such as warfarin, aspirin, clopidogrel, prasugrel, etc. Alarming, thrombotic and inflammatory complications persist in patients on ACT/APT, while their systemic administration brings the danger of hemorrhagic complications necessitating close patient monitoring. With the prevalence of cardiovascular diseases on the rise and the aging of the population, the problem is only poised to become more severe, and the need for a solution—more acute [2-6].

Failure to produce a hemocompatible material for vascular implants, or to offer a reliable protocol for in vitro predictive material hemocompatibility testing, is well-recognized and has been widely discussed in the literature [2-4, 6]. Over the last several decades, it led to the diminishing interest of clinicians and funding agencies in the material hemocompatibility research.

Recent years have seen significant advances in the understanding of coagulation, thrombosis, and platelet functions; interactions between hemostatic and inflammatory cascades and the role these interactions play in the adverse reactions to materials; and the role of platelets in non-hemostatic, regenerative processes. These advances allow the examination of the material hemocompatibility problem in a new light and open new avenues of investigation. This prompted several of us to organize a series of blood-biomaterial interaction conferences with the goal of bringing together clinical, academic, and industrial researchers working on the problem and reinvigorating the material hemocompatibility field. Their focus is on understanding the underlying mechanisms as the means to further advances. The first one took place in 2014 in Frejus,



France. The second meeting in the series, **2017 Blood-surf**, took place in Clemson, SC, USA in September 2017 with IUPAC program support in New Directions in Chemistry. A sequel is planned for 2020. In this report, we briefly summarize key aspects of the 2017 meeting. Details can be found in the recent *Opinion* paper based on the meeting [6] and the earlier review [4].

The key highlights of the 2017 meeting include presentations by the clinicians, Eugene Langan (Greenville Health System, SC, USA) and Lawrence “Skip” Brass (University of Pennsylvania, USA). The former set the stage by drawing attention to the problems with the existing arterial grafts in patients who receive ACT/APT and articulating the unmet clinical needs. The latter presented clinical cases of patients with hyper- and hypocoagulable states, highlighting the difficulties encountered by clinicians needing to introduce devices (catheters) into such patients as a part of the treatment, and discussed recent developments in the clot topology and regulation of platelet activity in the forming clot.

Interactions between coagulation, inflammation, and complement systems, introduced by Maud Gorbet (University of Waterloo, Canada), formed a strong theme throughout the conference. There is recognition that while platelets are the key players in response to the materials, they are not the whole story.

A similarly recurring topic focused on standardization of hemocompatibility testing and measurements discussed by several speakers. Progress that was made *vis-à-vis* the most recent revision of the ISO10993-4 standards was discussed by Mike Wolf (Medtronic, USA). Yet, much remains to be done on the side of donor variability, anticoagulation standardization, and other testing aspects. Here, the FDA, represented at the meeting by Qijin Lu (who received no financial support from the meeting to avoid potential conflicts of interest), needs to play a greater role in the standardization efforts, but there are many variables that remain poorly understood; hence the research community is expected to make progress that would form the basis of informed decisions by regulatory agencies such the FDA. A significant advance in this direction

was presented by Steffen Braune (Helmholtz-Zentrum Geesthacht, Germany), who discussed their recent (double-blind) round-robin study of platelet adhesion to various biomaterials comparing several different laboratories [7]. Funding agencies, take note: more studies of that type are sorely needed in all the aspects of material hemocompatibility research; not only testing, but also mechanistic studies. On one hand, a concrete conclusion emerged from the discussion of standardization: anticoagulants used in the blood-bio-material interaction studies need to be titrated in a donor-specific manner based on the measurements of coagulation system activity in the specific donors. On the other hand, inconsistencies continue to plague the interpretation of results: while Buddy Ratner in his talk highlighted the history of positive experience with the hydrophobic, perfluorinated materials in vascular implants, the work of Steffen Braune suggested the opposite. The resolution of this apparent contradiction must await the emergence of reliable parameters predicting *in vivo* material performance from *in vitro* tests. The need for such parameters was discussed by various speakers, as was the need to develop proper negative controls for *in vitro* testing and some basic guidelines for developing *in vitro* tests. These include the focus on surface- and solution-phase reactions, as already shown by Kusserow [8], and on various aspects of coagulation, inflammation, and complement systems. High-throughput, microfluidic, multiparametric testing methods combined with systems-based data interpretation, championed by Scott L. Diamond (University of Pennsylvania, USA), appear to provide a useful approach for mechanistic investigations of materials, while computational tools become indispensable once one moves from materials to complex implants, as highlighted in the talk by Ali Azadani (University of Denver, CO, USA).

Different strategies for developing actively anticoagulant surfaces were presented by John Brash (McMaster, Canada) and Hitesh Handa (University of Georgia, USA). Last but not least, the topic of protein adsorption at surfaces of various materials—one with a long history—was revisited and extensively discussed. There is an acute need for developing a database of proteins adsorbed on different materials and correlating the composition of the protein layers to the biological responses, as well as for further mechanistic studies in the spirit of those presented by Chris Siedlecki (PennState, USA) and Robert Latour (Clemson, USA). See also further discussion in refs. [4] and [6].

The meeting also included a session on new methods, where in particular the biological applications of

time-of-flight secondary ion mass spectrometry (ToF-SIMS) were presented by Lara Gamble (University of Washington, Seattle, USA) [9] presentations by post-docs and young faculty members, a poster session with students' poster presentations and awards, and a round-table discussion where further steps, including the plans for the 2020 meeting, were discussed.

Bloodsurf2017 achieved its original goal: to bring together clinicians and researchers working on hemocompatibility. The meeting received strong support from NIH and IUPAC, Clemson University, industry, and societies such as the ISTH and AVS. The proposal for the 2020 was enthusiastically met by the participants, signaling renewed interest in hemocompatibility problem of bright young minds.

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Ilya Reviakine <reviakin@uw.edu>, from University of Washington, Seattle, WA and Robert Latour, from Clemson University, were co-organizers of Bloodsurf2017.

Advanced Polymers via Macromolecular Engineering

by Aneli Fourie

The 13th International Conference on “Advanced Polymers via Macromolecular Engineering” (APME 2019) was held in the beautiful, historic town of Stellenbosch in South Africa from 15-18 April 2019.

A satisfactory number of delegates (180 participants) participated, representing 25 countries other than South Africa. Other western countries represented were Australia, Belgium, Brazil, Canada, China, France, Germany, Hungary, Ireland, Israel, Italy, Korea, Malaysia, Nigeria, Portugal, Russia, Saudi Arabia, Singapore, Spain, Switzerland, The Netherlands, Turkey, United Kingdom and USA. 72 students actively participated in APME 2019.

The APME 2019 Conference was opened by Yusuf Yagci, IUPAC Representative, Istanbul Technical University, Turkey, and Eugene Cloete, Vice-Rector (Research, Innovation and Postgraduate Studies, University of Stellenbosch, South Africa).

92 talks were presented (including 12 plenary/key-note speakers, 41 invited speakers and 39 oral submissions), by experts in their field, reporting the state-of-the-art in various fields, often encompassing the last few years of research. All others were accommodated in a lively poster session especially popular for student presentations.

41 Posters of a high standard were selected and presented at the poster session on Tuesday, 16 April. Three young scientists (MSc / PhD level) were awarded poster prizes sponsored by The Royal Society of Chemistry.

- **Lisa Fortuin**, University of Stellenbosch; “Biodegradable polymeric prodrugs for the targeted delivery of artemether- lumefantrine”
- **Jana Kohn**, Humbolt-Universität zu Berlin; “Expanding chemical space of mussel-inspired polymerization toward multifunctional monomers”
- **Elizalde Iraizoz Fermin**, University of Basque Country, Spain; “Dynamically crosslinked thermos-responsive polyurethanes”

Wiley-VCH: Macromolecular Journals sponsored two prizes for best talk and were awarded to the following young scientists (MSc/ PhD level):

- **Hannes Houck**, Ghent University, Belgium; “Light-stabilised dynamic materials”
- **Kristina Pflug**, University of Hamburg, Germany; “Closing the circle of microstructure and polymer properties for polyethylene via a combined analytical and modelling approach”

An Elsevier Workshop was presented by Christiane Barranguet entitled “How to produce an international publication: Getting published & Promoting your work.”

The conference chairs comprised of Bert Klumperman (University of Stellenbosch, South Africa), Munmaya Mishra (Altria – Center for Research & Technology, USA) and Yusuf Yagci (Istanbul Technical University, Turkey). The local and programme committee comprised of Bert Klumperman, Albert van Reenen, Harald Pasch and Peter Mallon (University of Stellenbosch, South Africa). The scientific committee comprised of Michel Baltas (CNRS, University of Toulouse, France), Dominique Bonnet (University of Strasbourg, France), Gilbert Lassale (Evotec, France), Sebastien Papot (University of Poitiers, France), Michel Perez (Pierre Fabre, France), Janos Sapi (SCT & University of Reims-Champagne-Ardenne, France), Luc van Hijfte (SCT & Novithera, France). The scientific advisory board comprised of Lian Hutchings (University of Durham, United Kingdom), Eva Harth (University of Houston, USA), Jean-Francois Lutz (Institut Charles Sadron, France), Fiilp Du Prez (Ghent University, Belgium) and Hölger Schonherr (University of Siegen, Germany).

More details and full program are available online <http://academic.sun.ac.za/apme>

Aneli Fourie, conference Secretary <aeef2@sun.ac.za>

Polymer for Sustainable Development

by Chin Han Chan, Holger Schönherr, and Jyoti Giri

POLY-CHAR 2019 [Kathmandu], also known as International Polymer Characterization Conference, under the auspices of the Scientific Committee of POLY-CHAR and IUPAC, was hosted by the Nepal Polymer Institute (NPI) and the Research Centre for Advance Science and Technology (RECAST), Tribhuvan University, Nepal at Park Village Resort, Kathmandu, 19-23 May 2019. The theme of the conference was “Polymer for Sustainable Development.”

POLY-CHAR is a nonprofit, non-governmental organization devoted to create a friendly environment to share information, organize student exchange and cooperation, to hold international meetings and to provide a platform in the field of Materials Science, in particular Polymer Materials Science and Technology, for scientists from all over the world, disregarding where they are from. An important goal of POLY-CHAR is to offer a conference for PhD students and young researchers, so that they will create their own scientific



Opening ceremony. Front row: 2nd from left – Prof. Dr. Rameshwar Adhikari (Organizing Chairman of POLY-CHAR 2019); 2nd from right – Prof. Dr. Jean-Marc Saiter (President of POLY-CHAR Scientific Committee); and (far right) Prof. Michael Hess.

networks and experience a true scientific community. POLY-CHAR is rooted in polymer synthesis, characterization, processing, application, recycling, education and its environmental/social consequences.

A total of 7 keynote speakers, 30 invited speakers, 28 oral speakers, 45 poster presenters and 50 participants from 16 countries with more than 50 % of international participants participated in POLY-CHAR 2019 [Kathmandu]. This inaugural conference conducted two special symposia on

1. NMR on Biomolecules, and
2. Polymers Nanotechnology for Nepal.

The conference presentations were organised under the themes of:

1. Advances in Polymer Synthesis
2. Biomolecules, Biomedical Materials and Biotechnology
3. Nanomaterials, Smart Polymers
4. Polymer Characterization
5. Polymer Degradation, Recycling and Environment Protection
6. Polymer Electronics and Bioelectronics
7. Polymer Physics, Theory and Simulations
8. Rheology and Processing

The inauguration of the conference was made by Jhala Nath Khanal (Former Prime Minister of Nepal); the other dignitaries were Er. Ganesh Shah (former Science Minister of Nepal), Rajesh Pandit (President of Nepal Polymer Institute), Rameshwar Adhikari (Organizing Chair of POLY-CHAR 2019), Jean-Marc Saiter (President of POLY-CHAR Scientific Committee), Michael Hess (Vice President of POLY-CHAR Scientific

Committee) and Melissa Chan Chin Han (IUPAC Representative).

The POLY-CHAR Short Course was held on the first day of the conference, including five graduate-level tutorial presentations on the following topics:

- PVT for characterization of polymers; (Jürgen Pionteck, Leibniz Institute of Polymer Research Dresden, Germany)
- Thermal analysis: a focus on thermogravimetry; (Jean-Marc Saiter, Onyx Development, Nutriset Group, France)
- Viscoelastic properties of polymers; (Michael Hess, University of North Texas, USA)
- Morphology, mechanical properties and nanoscale analysis of polymer systems with atomic force microscopy; (Holger Schönherr, University of Siegen, Germany)
- Electron microscopic methods to investigate morphology and micromechanical processes of polymers; (Sven Henning, Fraunhofer Institute for Microstructure of Materials and Systems, Germany)

Outstanding researchers were honored with the POLY-CHAR awards, which are named in honour of three distinguished Nobel Laureates:

The Richard Robert Ernst Award went to Chuanliang Feng, Shanghai Jiaotong University, China; the Jean-Marie Lehn Award went to Ralph Paul Cooney, The University of Auckland, New Zealand and Pierre-Gilles de Gennes Award was awarded to Mehrdad Negahban, University of Nebraska, USA for their exemplary research work.

The POLY-CHAR Best Oral Presentations were awarded to:

- Jiji Abraham, Mahatma Ghandi University, Kottayam, India, for her work on Ionic liquid modified carbon nanotube based styrene butadiene rubber nanocomposites
- Rongyu Xia, Peking University, China for his work on Effect of fiber treatment and process and process variation on morphology, thermal, mechanical and water absorption behaviours of natural fiber nanocomposites
- Netra Lal Bhandari, Tri-Chandra Campus, T.U. Nepal, for his work on Steering elastic sheerhorizontal waves by tunable locally resonant metasurface
- Bhim Kafle, Kathmandu University, Nepal, for his work on Reduced graphene oxide (rGO) films for hole transport layer for perovskite solar cells.

Three IUPAC Awards for Best Student Posters were awarded to:

- Arpita Roy, IIT (ISM) Dhanbad, India for his work on β -cyclodextrin based dual responsive hydrogel for colonic drug delivery
- Achyut Nepal, Department of Physics, Amrit Science Campus, Kathmandu, Nepal for his work on TiO_2 nanoparticles as an electrode of dyes sensitized solar cells (DSSC)
- Chanda Bhandari, College of Biomedical Engineering and Applied Sciences, Kathmandu, Nepal, for her work on Application of zinc oxide nanoparticles loaded with slug slime as surgical glue for wound closure and healing

Three POLY-CHAR Best Student Posters were awarded to:

- Lucas Grossmann, Hof University of Applied Science, Hof, Germany for his work on Investigation of the influences of composition and processing of pressure sensitive adhesive polymeric materials laminated with textiles
- Tabli Ghosh, IIT Guwahati, Guwahati, India, for her work on Development of non-toxic magnetic cellulose nanofiber dispersed chitosan based edible nanocoating
- Yuchen Shi, Hefei National Laboratory for Physical Sciences at the Microscale, Hefei, China, for his work on Novel electrochromic-fluorescent bi-functional devices based on aromatic viologen derivatives

The coming POLY-CHAR conferences were planned for POLY-CHAR 2020 [Venice], Italy, 18-22 May 2020 and POLY-CHAR 2021 [Auckland], New Zealand, 25-29 January 2021.

Macrocyclic and Supramolecular Chemistry

by Pierangelo Metrangolo

The **14th International Symposium on Macrocyclic and Supramolecular Chemistry** (ISMSC2019, www.ismsc2019.eu) was held from 2 to 6 June 2019 in Lecce, Italy. The symposium was organized by Politecnico di Milano and Fondazione Politecnico di Milano, and chaired by Pierangelo Metrangolo, Francesca Baldeli Bombelli, and Giancarlo Terraneo. Co-organizers of the event were the local academic and research institutions, such as Università del Salento, and its School of Advanced Studies, ISUFI, the Nanotechnology Institute (Nanotec) of the National Research Council (CNR), and the Center for Biomolecular Nanotechnologies (CBN@UniLe) of the Italian Institute of Technology (IIT).

The symposium was attended by 712 scientific participants from 43 different countries. The program included 2 Nobel Laureate lectures (45 minutes each), 3 Award lectures (40 minutes each), 22 keynote talks (30 minutes each), and 24 invited talks (20 minutes each). In addition, there were 12 oral (15 minutes each) and 24 short paper (5 minutes each) contributions selected by the organizers from the submitted abstracts. The poster session enabled 550 participants to share their work in this exciting meeting for the supramolecular chemistry community. In particular, ISMSC2019 hosted lectures from the 2016 Nobel Laureates in Chemistry (Sir James Fraser Stoddart, and Bernard L. Feringa), as well as from the 2019 Izatt-Christensen Award (Luisa De Cola), Cram-Lehn-Pedersen Prize (Xiaopeng Li), Sessler Early Career Researcher Prize (Ross Stewart Forgan), and the Natural Product Reports Emerging Investigator Lectureship (Konrad K. Tiefenbacher) winners.

The symposium received the endorsement, among others, of IUPAC, the International Year of the Periodic Table of Chemical Elements (IYPT2019), the European Chemical Society (*EuChemS*), the Italian Chemical Society (SCI), and the Materials Research Society (MRS). As far as IYPT2019 is concerned, ISMSC2019 was selected by IUPAC as the venue for the announcement of ten elements of the Periodic Table of Younger Chemists celebrating IUPAC 100.

IUPAC supported the Microsymposium **“New Directions in Supramolecular Chemistry: Nanomedicine”**, which was held within the ISMSC2019 program and has shown how, recently, Supramolecular Chemistry (*i.e.*, use of inter-molecular interactions to build-up self-assembled systems) has been exploited



ISMSC2019 group picture at Monastero degli Olivetani, Lecce, Italy.

for pioneering new directions in bio-engineering and nanomedicine. IUPAC support allowed the participation of seven young scientists coming from underdeveloped countries.

Other funding agencies supported ISMSC2019 such as the International Union of Crystallography (IUCr), the Organization for the Prohibition of the Chemical Weapons (OPCW), the US Army, the Boehringer Ingelheim Stiftung, and the World Society of Intravenous Anaesthesia (WorldSIVA). This support, along with others coming from National, Regional, and Local institutions and associations, covered most of speakers' expenses and supported the participation of 21 young scientists with grants. Furthermore, the ISUFI college of the local university offered 31 free accommodations to students. Finally, several companies and most of the chemistry scientific publishers sponsored the symposium, e.g., the Royal Society of Chemistry (RSC), the American Chemical Society (ACS), Wiley, Springer-Nature, Elsevier, and MDPI, and offered more than 30 prizes to be awarded to the best posters.

In general, the conference covered a wide range of topics such as organic electronics, nanotechnology, biology, medicine, and materials science, in which supramolecular chemistry was the common tool for developing innovative materials, devices, macromolecules, nanovectors, etc. This symposium showed forcefully how supramolecular chemistry is flourishing, crossing traditional borders, and moving towards new

interdisciplinary areas of research at the interface between chemistry, medicine, biology, and materials science.

As far as outreach is concerned, during ISMSC2019, a public lecture was delivered by Sir James Fraser Stoddart to present the world of supramolecular chemistry and the long scientific journey to the Nobel Prize in Chemistry 2016. More than 800 high school students, as well as citizens attended this lecture.

The event passed in an informal and friendly atmosphere with stimulating discussions during the sessions as well as in the coffee breaks, lunches, poster sessions, and banquet. Furthermore, ISMSC2019 was spread over several historical venues in the city of Lecce, such as the city theater, Teatro Apollo (Opening Ceremony), Monastero degli Olivetani (lunches and poster sessions), Torre del Parco (speakers' dinner), and Chiostro dei Domenicani (Banquet), which gave the unique opportunity to experience the architectural and historical beauties of this southern part of Italy.

ISMSC2019, beyond providing a platform for scientists from different disciplines to brainstorm and promote cross-disciplinary collaborations, represented a great opportunity for junior researchers and PhD students to present their work and discuss new ideas with well-established leaders in their field of research.

The 15th edition of this symposium, ISMSC2020 (www.ismsc2020.org), will be held in Sydney, Australia, 12-16 July 2020, chaired by Kate Jolliffe.

Crop Protection Chemistry

by Ken Racke, Pieter Spanoghe, Nathan De Geyter, and Bipul Saha

The 14th IUPAC International Congress of Crop Protection Chemistry was held 19-24 May 2019 in Ghent, Belgium (www.iupac2019.be). This Congress Series has been ongoing approximately every four years since 1967 and is managed by the IUPAC Chemistry and the Environment Division (Div VI) Advisory Committee on Crop Protection Chemistry. The 14th Congress was organized by the University of Ghent (UGent), under the leadership of Pieter Spanoghe and Nathan De Geyter, and held at the International Convention Centre in Ghent. This Centre lies in a tranquil oasis in the middle of Ghent's largest park.

The Congress presented a unique opportunity to enable knowledge exchange and research cooperation on all scientific aspects of crop protection between the most important actors in industry, academia, and government, both related to research and practical application. Around 1572 top international experts from more than 80 countries turned up in Ghent to share their research and perspectives on sustainable crop protection. They enjoyed five days of high quality, diverse and innovative scientific programming, including lectures, posters, and debates. To link theory to practice, a total of eleven "sustainable agricultural excursions" were organized to demonstration farms and crop protection chemistry research sites of companies, universities, and farm advisory services.

To enrich the Congress and promote cross-fertilization between different sectors, the programs of two related conferences were also embedded within the IUPAC Congress. These included a 2-day "Crop Protection Regulatory Workshop" organized by the European Crop Protection Association (link with regulation) and a 1-day "UGent International Symposium on Crop Protection" (link with innovations in alternative crop protection). In addition, a meeting of the Division VI Advisory Committee on Crop Protection Chemistry was held during the Congress.

IUPAC Award

A highlight of the Congress opening ceremony was the presentation of the biennial "IUPAC International Award for Harmonized Approaches to Crop Protection Chemistry." This year, the award was presented to honor the late Dr. Mark R. Lynch, who had a storied career of more than 45 years as a regulator, national and international work group leader, and consultant. Dr. Lynch's base appointment was with the Irish Department of

Agriculture, and from there he played an instrumental role in the development of harmonized EU legislation and supporting guidance related to pesticide approval via Directive 91/414 EEC. He also led the OECD in implementation of a "Vision for Pesticides", which yielded the foundational guidance documents and tools for international collaboration and work-sharing. Dr. Lynch's award was received by his daughter and granddaughter, and an honorary lecture was presented by Dr. Gordon Rennick of the Irish Department of Agriculture, himself a noteworthy international expert on regulation of crop protection products.

Scientific Program

The theme of the IUPAC Congress was "*Crop Protection: Education of the Future Generation*" and the expansive program was organized around 10 main scientific topics:

1. Emerging issues and challenges
2. Novel agricultural technologies
3. Discovery and optimization of crop protection products
4. Formulation and application technologies
5. Non-dietary human health hazards, exposure and risk
6. Food quality and safety
7. Environmental fate, transport, and metabolism
8. Ecosystem and ecological risk assessment
9. Mode of action and resistance
10. Stewardship, regulation, and communication

The scientific program reflected well the traditional strengths of the IUPAC crop protection chemistry



NextGen Agri-preneurs: Enthusiastic participation of young scientists in the IUPAC 2019 NextGen summit



Longtime IUPAC member Keiji Tanaka discussing a poster presentation.

congresses, including plenary lectures, invited lecture sessions, and poster sessions. There were nine plenary lecturers representing all major sectors and ranging in diversity from a Nobel laureate chemist to a potato farmer.

- *Research excellence through innovation: Doing one's own thing*; Fraser Stoddart, Northwestern University, USA
- *Cyclic lipopeptides: versatile molecules for plant disease control*; Monica Höfte, Ghent University, Belgium
- *History, status and potential of natural products for pest management and plant health?* Pam Marrone, Marrone Bio Innovations Inc., USA
- *Emerging food safety risk—new challenges for Latin American countries*; Nuri Gras, Chilean Food Safety and Quality Agency, Chile
- *Precision agriculture in practice*; Jacob van den Borne, van den Borne Potatoes, The Netherlands
- *PERFECT UPportunities for REALsearch in AgriCOOLture*. Hlami Ngwenya, University of Free State, South Africa
- *The EU's plant protection policy: Lessons learned and next steps*; Vytenis Andriukaitis, EU Commissioner on Food & Health, European Commission, Lithuania
- *Research and development of green pesticides in China*; Xuhong Qian, East China Normal University, China
- *Block chain trust*; David Zaruk, Odisee University College, Belgium

The heart of the scientific program consisted

of some 300 invited lectures along with more than 700 posters, the latter including innovative e-poster boards. To recognize excellence in poster presentations, 21 poster prizes were also awarded by an international scientific jury. In addition to innovation and new product development, many researchers reported on studies of the potential effects of crop protection products on human health and the environment.

An innovative and highly popular aspect of the scientific program was provided by the “lively plenary debates” organized at the end of the afternoon sessions. These debates were organized around “hot topics” of contemporary interest for crop protection chemistry:

- Crop protection science-based facts and fact-based policy.
- Farming and crop protection in 10, 20, and 30 years.
- Communication on agrosience to the broad public.
- Engaging the next generation for agriculture.

Each debate topic featured a panel of experts drawn from various sectors, and debates were moderated by award-winning international journalist and broadcaster Femi Oke (BBC, CNN, Sky TV). Her highly energetic style and use of provocative questions led to lively discussion and diverse perspectives among panelists and good engagement from the audience, who were also able to intervene with questions.

Young Scientists

In keeping with the Congress theme of “Education of the Future Generation,” significant attention and resources went toward the engagement of young scientists. This included designation of quotas for the participation of young researchers in the various invited lecture sessions.

The organizers felt it was essential to involve the next generation of crop protection leaders and to show them how important their role is for the future of agriculture. Thus, a special international youth competition and summit were organized as part of the Congress and branded as the “IUPAC Next Generation Program” or “NextGen” (<https://nextgen.iupac2019.be/>). The competition invited students and recently graduated crop protection chemists and agro-ecologists to share their innovative ideas on crop protection. More than 500 proposals were submitted from all over the world, of which 187 were posted to the IUPAC NextGen website for viewing (>200 000 views) and initial voting by website visitors (>83 000 visitors). Based on an expert panel review, 50 laureates were selected to participate in the “Next Generation Agri Summit”, which

Conference Call

ran as part of the IUPAC Congress program. Finally, five young entrepreneurs in agriculture were selected as “N-GAGE Champions.” These champions were able to present their innovative ideas at the Congress and each will receive guidance for a year and 5000 € in funding to effectively realize their innovative concept.

- *Modern crop protection using tools farmers have at hand*; Simon Appeltans, Belgium
- *The management of plant diseases using botanicals and ICT in Nigeria*; Apolowo Oluropo Ayotunde, Nigeria
- *Pestisorb remediation of pesticide rinsate using activated carbon derived from agricultural wastes*; Eric Jhon Cruz, Philippines
- *Adapting nanotechnology as versatile instrument for the development of eco-friendly pest control methods with semiochemicals*; Bruna Czarnobai De Jorge, Brazil
- *Drone technology to tackle pests in Botswana*; Antonette Ncube, Botswana

Communications and Social Media

To enrich the experience of attendees and reach many other stakeholders, Congress organizers made masterful use of the latest in communication and social media technologies leading up to and during the Congress. This included development of a highly interactive Congress website, elaboration of the Congress program via a smartphone app, e-newsletters, a blog, posts to Twitter and Instagram, and live-streaming of key sessions.

In the run-up to the Congress, biweekly e-newsletters were sent to a database that grew to nearly 7000

international crop protection experts. The content of the newsletters contained both practical information and stories about innovations in crop protection research that partners wished to share with the crop protection community. These stories were also first posted via a blog associated with the Congress website.

Furthermore, there was extensive communication during the conference on social media, such as Twitter (@IUPAC2019 and @IUPACNEXTGEN) and Instagram (@IUPAC2019) with a joint reach of 1339 followers. Top tweets achieved more than 9000 views.

Opening ceremony, plenary lectures, and lively plenary debates were all live-streamed on-line, and video recordings of these events are now posted to YouTube (www.iupac2019.be/videos/).

In a fitting move, the closing ceremony included a smashing “Congress After-Movie” of key images and voices from the Congress (<https://youtu.be/lqNkiM1k088>).

What's Next?

Full papers and extended abstracts from the 14th IUPAC Congress will be published in the University of Ghent's *Communications in Agricultural and Applied Biological Sciences*. Selected papers have also been invited for publication in a special issue of the journal “*Pest Management Science*.”

The 15th International Congress of Crop Protection Chemistry will be organized in New Delhi, India, during 10-13 January 2023. Congress organization will be led by longtime IUPAC members Dr. N.A. Shakil and Dr. Jitendra Kuma, and early details are available via the Congress website at www.iupac2023.com.



Feature Articles Wanted
Contact the editor for more information
at <edit.ci@iupac.org>.

Where 2B & Y

Chemistry Conference for Young Scientists

19-21 February 2020, Blankenberge, Belgium



The 15th edition of ChemCYS, the Chemistry Conference for Young Scientists, will take place from 19-21 February 2020 on the Belgian coast in Blankenberge. ChemCYS is an international, biennial conference, which aims to create a platform for final-year master students, Ph.D. students and young post-docs to present early results of their research.

We accept oral and poster entries from all fields of chemistry and life sciences. Accepted submissions will be assigned to one of the following six topical sessions:

- Analytical and Environmental Chemistry
- Life Sciences
- Inorganic Chemistry
- Macromolecular and Materials Chemistry
- Organic and Organometallic Chemistry
- Physical and Theoretical Chemistry

The best oral and poster presentation of each session will be awarded.

Furthermore, we're proud to announce confirmed lectures by Prof. **Sarah E. O'Connor** (Planck Institute

of Chemical Ecology, Germany), Prof. **Javier García Martínez** (Founder and Chief Scientist of Rive Technology Inc, Boston MA, USA) and Prof. **Krzysztof Matyjaszewski** (Carnegie Mellon University, Pittsburgh, PA, USA).

ChemCYS also features parallel soft skill seminars and KaféCV, our entrance level networking event where participants get to know various companies and their recruitment policies. KaféCV enhances career development by exchange of experiences between senior chemists and the next generation of chemists, offering a peek into the life of a scientist in a professional environment.

ChemCYS is organised by the youth division of the Royal Flemish Chemical Society (Jong-KVCV) and is officially endorsed by IUPAC and EuChemS.

Registrations are open now at www.chemcys.be

Visas

It is a condition of endorsements that organizers of meetings under the auspices of IUPAC, in considering the locations of such meetings, should take all possible steps to ensure the freedom of all *bona fide* chemists from throughout the world to attend irrespective of race, religion, or political philosophy. IUPAC endorsement implies that entry visas will be granted to all *bona fide* chemists provided application is made not less than three months in advance. If a visa is not granted one month before the meeting, the IUPAC Secretariat should be notified without delay by the applicant.

How to Apply for IUPAC Endorsement

Conference organizers are invited to complete an Application for IUPAC Endorsement (AIE) preferably 2 years and at least 12 months before the conference. Further information on granting endorsement is included in the AIE and is available upon request from the IUPAC Secretariat or online.

www.iupac.org

Mark Your Calendar

2019 after October 15

15-18 October 2019 • Coordination Chemistry • Kuala Lumpur, Malaysia

7th Asian Coordination Chemistry Conference (ACCC7)

Chair: Geok Bee Teh, E-mail: sharonteh2009@gmail.com; Contact: ACCC7 Secretariat, c/o Institut Kimia Malaysia, E-mail: secretariat@accc7.org.my, <https://accc7.org.my>

5 Dec 2019 • IYPT2019 Closing • Tokyo, Japan

The Official IYPT2019 Closing Ceremony will be hosted by Science Council of Japan IUPAC subcommittee; <http://www.iypt2019.jp/eng/index.html>



15-18 December 2019 • Bioorganic Chemistry • Shenzhen, China

12th International Symposium on Bioorganic Chemistry (ISBOC-12)

C-Chairs: Zhen Xi, Nankai University, E-mail: zhenxi@nankai.edu.cn and Yuyang Jiang, Tsinghua Shenzhen International Graduate School, E-mail: jiangyy@sz.tsinghua.edu.cn • <http://www.sz-isboc.com/>

2020

5-10 January 2020 • Electrochemistry GRC • California, USA

Bridging Scales in Electrochemical Materials and Methods Applied to Organic and Inorganic Chemistry, Catalysis, Energy and Biology

Janine Mauzeroll (chair), McGill University, Montreal (Québec), Canada, E-mail: Janine.mauzeroll@mcgill.ca, <https://www.grc.org/electrochemistry-conference/2020/>

7-10 January 2020 • Agrochemicals Protecting Crops, Health and Natural Environment • New Delhi, India

Discovery and development of synthetic and natural products for pests management

N. A. Shakil, E-mail: iamshakil@gmail.com, IARI, New Delhi • 110 012 India • <http://www.apchne4.com>

19-21 February 2020 • Chemistry Conference for Young Scientists • Blankenberge, Belgium

Chair: Karel Haesevoets, secretary@chemcys.be, Koninklijke Vlaamse Chemische Vereniging vzw, support@chemcys.be, www.chemcys.be

5-9 July 2020 • MACRO2020 • Jeju Island, Korea

48th World Polymer Congress

Chair: Doo Sung Lee, ex-President, PSK; program chair: Jun Young Lee; secretary general: Dong June Ahn (ahn@korea.ac.kr); E-mail: secretariat@macro2020.org; www.macro2020.org

16-21 August 2020 • Theoretical and Computational Chemists • Vancouver, Canada

12th Triennial Congress of the World Association of Theoretical and Computational Chemists

Chair: Russell J. Boyd, Dalhousie University, E-mail russell.boyd@dal.ca; contact Chemical Institute of Canada (CIC), 222 Queen St, Suite 400, Ottawa, Ontario, Canada, toll free: 1-888-542-2242, <http://watoc2020.ca>

13-17 July 2020 • Chemistry Education • Cape Town, South Africa

26th IUPAC International Conference on Chemistry Education (ICCE 2020)

Contact/chair of the local organizing committee: Bette Davidowitz <Bette.Davidowitz@uct.ac.za>, Chemistry Department, University of Cape Town, Rondebosch, South Africa, www.icce2020.org.za

1-4 November 2020 • Bioanalytical and Environmental Analyses • Siem Reap, Cambodia

Joint Meeting of the 18th Asia Pacific Symposium on Microscale Separation and Analysis and 17th International Interdisciplinary Meeting on Bioanalysis (APCE & CECE 2020)

Doo Soo Chung (Chair of Local Organizing Committee), Department of Chemistry, Seoul National University, E-mail: dschung@snu.ac.kr, www.apce-cece.org

10-13 November 2020 • POLYSOLVAT • Toyonaka, Japan

Polymer-solvent Complexes and Intercalates (POLYSOLVAT-13)

Co-chairs: Fumitoshi Kaneko, Graduate School of Science, Osaka University, Toyonaka, Osaka 560-0043, Japan, E-mail: toshi@chem.sci.osaka-u.ac.jp and Takahiro Sato, Graduate School of Science, Osaka University, E-mail: tsato@chem.sci.osaka-u.ac.jp • Web tba

2021

13-20 August 2021 • IUPAC World Chemistry Congress/General Assembly • Montréal, Québec, Canada

Frontiers in Chemistry: Chemistry for Health, Energy, Sustainability and Society • www.iupac2021.org

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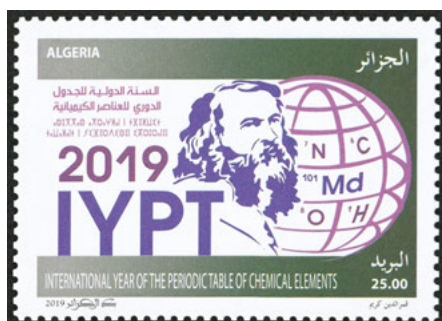
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See also www.iupac.org/publications/ci/indexes/stamps.html

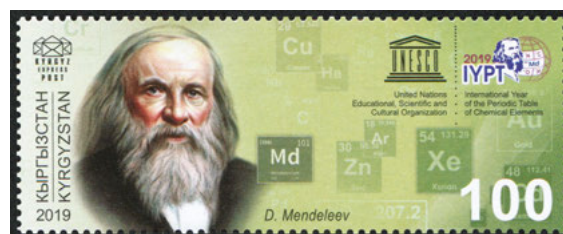
IYPT and The Mother of All Tables

A few years ago, the International Year of Chemistry (2011) was celebrated throughout the world with the organization of thematic conferences and symposia, special activities for children, the publication of a myriad of articles and reviews, and, of course, the release of postage stamps by many countries. Likewise, the International Year of the Periodic Table (IYPT) presents now another rare opportunity to relate the history of chemistry and showcase its societal benefits to a worldwide audience. As originally proclaimed by the United Nations and UNESCO, the IYPT also offers an incentive to promote international cooperation in the basic sciences for sustainable development and science education.

The first country to philatelically recognize the IYPT was Algeria, where a stamp with a rather mundane design was issued shortly after New Year's Day, on 2 January 2019. The stamp simply features the IYPT logo, with the likeness of Dmitri Mendeleev and a globe incorporating the chemical symbols of mendelevium and the four most common elements found in living organisms (hydrogen, carbon, nitrogen, oxygen) prominently displayed.



A week later, a much more interesting stamp highlighting the chemical symbols of vanadium, tungsten, and platinum, the three elements whose discoveries have strong ties to Spain, was issued by *Correos*, the Spanish postal service. It turns out that the discovery of vanadium is usually credited to the Spanish mineralogist Andrés Manuel del Río (1764-1849), who spent



most of his professional life in Mexico. In 1801 he analyzed a series of lead-containing mineral specimens from the state of Hidalgo's Purísima del Cardenal mine and ascertained the presence of the new metallic element, which he initially named panchromium and later erythronium. The identity of the new element was confirmed some 30 years later by the Swedish chemist Nils Gabriel Sefström (1787-1845), who named it vanadium in honor of Vanadis, the Scandinavian goddess of love and beauty.

Tungsten, the only chemical element to be actually discovered in the Spanish mainland, was isolated in 1783 by the Spanish chemist Juan José Delhuyar (1754-1796) and his younger brother Fausto (1755-1833). The symbol of the element (W), of course, reminds us of wolfram, the original name proposed by the Delhuyar brothers, which is still the preferred name for element 74 in Spain, Germany, Scandinavia, and other countries.

Platinum, a relatively rare element usually found associated with nickel and copper ores, was already known to pre-Columbian natives in the area of present-day Colombia and Ecuador. However, the "European" or "modern" discovery of platinum is often ascribed to the Spanish scientist and explorer Antonio de Ulloa (1716-1795), who was a member of the Geodesic Mission to South America sponsored by the French Academy during 1735-1744. Upon his return to Spain, de Ulloa wrote extensively about the expedition and described for the first time in 1748 some of the physical and chemical properties of the noble metal.

The IYPT was also commemorated with colorful stamps issued by Kyrgyzstan and the Republic of Moldova on April 12 and May 23, respectively. Both depict the logos of the IYPT and UNESCO, the latter being not only a key stakeholder of this year's events but also the site of the Opening Ceremony that was held in Paris on 29 January. In addition, the stamp from Kyrgyzstan

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shows a portrait of Mendeleev and the chemical symbols of mendelevium, zinc, copper, helium, argon, and xenon, among other elements. In turn, the one from Moldova includes a picture of a Rubik's cube with different elemental symbols in each of its faces, an appealing tribute to the periodic table since it solved the puzzle of organizing the chemical elements!

Last but not least, Hungary and Bulgaria also released IYPT stamps, on June 3 and 24, respectively. Both present images of Mendeleev and different versions of the periodic table. Whereas the Hungarian stamp includes a small illustration of Mendeleev's original (1869) manuscript of the periodic table, the Bulgarian one displays in the foreground the symbols of all the elements, from hydrogen to oganesson.



It remains to be seen which other countries issue stamps to honor the sesquicentennial of the periodic table later this year. And I have to wonder if some of the *other* chemistry anniversaries taking place in 2019, such as the centennials of IUPAC or Primo Levi's birth, or perhaps the discovery of phosphorus 350 years ago, will also be publicly acknowledged with the release of postage stamps. In the meantime, to all chemophiles and periodic table enthusiasts out there, happy IYPT!

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