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# Recording the past, predicting the future: The periodic table 150 years on

The International Year of the Periodic Table of Chemical Elements in 2019 marks the 150th anniversary of the publication of Dmitri Mendeleev's periodic table. The periodic table – a classificatory tool, educational diagram and representation of elements – has since become one of the most ubiquitous and successful productions of European science, and is to chemistry as Darwin's theory of natural selection is to biology.[1] The periodic table is not only found in every chemistry laboratory and high school science classroom, but has also inspired a plethora of literary and cinematic interpretations. Acclaimed works of literature such as holocaust survivor, writer and chemist Primo Levy's *The Periodic Table,* as well as Oliver Sacks's much acclaimed *Uncle Tungsten* were inspired by it. Elements bromine and barium form the opening credits to the TV series *Breaking Bad*. More recently, the periodic table has even garnered its own song in a viral YouTube video.[2]

Aside from being an educational, organisational and predictive tool for aspiring and professional chemists, the periodic table is also a highly mediated record of the history of chemistry: the elements are named to commemorate its long genesis. Reflecting its indebtedness to ancient Greek alchemists, helium takes its name from Helios, god of the sun. Promethium is named after Prometheus, who stole heavenly fire and gave it to human beings – a substance without which the discipline of chemistry would never have existed. Nihonium was named in honour of Japan, the nationality of the team of scientists who first observed it. Americium, francium, darmstadtium and californium among others, likewise, take their names from places in which they were discovered, or that their discoverers wished to commemorate. Some elements have been named after individuals who made major contributions to chemistry, such as Glenn Seaborg, Albert Einstein, Nils Bohr, Ernest Rutherford, Alfred Nobel and, of course, Mendeleev.

Behind this neat version of the periodic table's history, lies centuries of discoveries, errors, controversies, successes and failures.[3] Within its own historical period, each iteration of the periodic table offers a record of scientific consensus, which has continuously changed as new findings have been made, errors been corrected and elements have been renamed or removed. To name one example, in the late 18th century, chemist Antoine Lavosier regarded light and heat to be elements.[1] The major player in this history of the modern periodic table is, of course, Dmitri Mendeleev, who organised the known elements by atomic weight and chemical affinities and is often credited as the 'discoverer' of the periodic system.

The word 'discovery', however, masques a long history of laboratory work, publication and debates, and myriad attempts at representing the elements. Mendeleev's periodic system was a complex organisational scheme that synthesised centuries of work in chemistry into a highly successful organisational, classificatory and predictive framework. It was one in a long lineage of attempts to 'make sense of the way in which particular elements enter into chemical bonding'[1]. The earliest attempts to classify the elements can be traced as far back as ancient Greece, in which the term 'element' denoted 'a "tendency" or "potentiality" that gave rise to the observable properties of the element', a definition which drew a distinction between its abstract and observable form.[1] In the 18th century, this abstract definition gave way to an empirical understanding, advocated by Robert Boyle and Antoine Lavoisier, who argued that an element should be defined as 'a material substance that has yet to be broken down into any more fundamental components by chemical means'[1].

Attempts to place the elements into tables are more recent. Since the 18th century, as Benjamin Cohen has argued, chemists have utilised tables as organisational tools for 'collecting the known and practical guides for directing work toward the unknown'[4]. In this period, they were indispensable tools in the laboratory, which mostly acted as guides that assisted chemists by making predictions based on known chemical affinities.[4] Perhaps the most famous of these early systems, is Antoine Lavosier's 1789 list of elements, and atomic theorist John Dalton's 1808 table of relative atomic weights.[4]

Learning to read these earlier tables often meant learning a new visual language.[5] Before 1813, many systems for organising the elements placed arcane alchemical symbols in relation to one another, but these were ultimately discarded due to the problems they posed for publication and communicability.[1,4] Right up to (and after) the publication of Mendeleev's system, the table itself as a diagram was not the only form of representation. Gmelin's 'remarkable system', published 26 years before Mendeleev's, for example, was also ordered according to atomic weight, but took a V shape.[1]

## The 1860s: Development of the modern periodic system

The critical decade for the development of the modern periodic table was the 1860s. In this decade, following the 'rationalization of atomic weights' at a seminal international congress of chemists in Karlsruhe, there were at least six 'discoveries' of the periodic system.[1] At this conference, more 'precise definitions of the concepts of atom, molecule, equivalent, atomicity, alkalinity' were discussed.[6] The six discoveries published in the years following Karlsruhe, were not revolutionary, but dependent upon the scaffolding provided by earlier chemists.[1] While some took the form of tables, others opted for entirely different visual strategies. The first was published by French geologist Alexandre-Émile Béguyer de Chancourtois in 1862. His model was three dimensional: a cylinder with elements arranged in descending vertical groups.[7] Unfortunately for him, printing a three-dimensional model on a sheet of paper proved challenging, which made it relatively incommunicable to large audiences.[1] Next, came William Odling and Julius Lothar Meyer, who both published their own tables in 1864. Perhaps most interestingly, in 1866, John Newlands utilised the model of a musical scale to organise the elements in a 'law of octaves'. Like the rhyming sound produced by each eighth note on a sequence, so too did every eighth element seem to correspond.[8] After Newlands, came Gustave Hinrichs's system, which depicted relationships between elements within a spiral.[1,9]

## Mendeleev's system: Publication and reception

Mendeleev's first periodic table was published in 1869. As is well known, Mendeleev organised elements according to atomic weight, and proposed that they exhibited 'an apparent *periodicity* of properties' when arranged in such a way.[1] An important and unique feature of his table were the gaps it left, which could be filled with future discoveries. As a recent article in the *Economist* put it, if 19th-century chemists could be considered as stamp collectors, Mendeleev provided 'an album in which to stick their discoveries'.[8]

As historians of science have long argued, scientific discoveries are never automatically accepted as 'breakthroughs' and subsequently diffused amongst the scientific community: their authority as 'truth' or 'facts' has to be constructed in a crucible of social, political, economic and epistemological forces.[10,11] Any theory also has to 'prove its value as a guide to ongoing research, and only after it does will it be incorporated into textbooks as part of the established knowledge of a science'[12]. Mendeleev's periodic table was no different. It took time for his system to gather attention, even in his native Russia. In Autumn 1869, for example, the president of the Russian Chemical Society, N.N. Zinin advised him 'to do "[real] work," meaning do something experimental, preferably on organic chemistry, which was the mainstream research discipline at that time'[12].

Despite this critique, over the next 20 years, Mendeleev's was to become the dominant periodic system. Key to its success was his treatment of time, and capacity to speculate.[6] Like his contemporaries, he drew upon past discoveries in order to organise his table, but unlike many others, he also looked towards the future, leaving spaces in which new elements could be added.[12] In November and December of 1870, he published two papers on 'the Natural System of Elements', which successfully predicted the 'properties of some undiscovered elements in detail'. This attracted significant attention within the local and international communities of chemists.[1] Mendeleev was fortunate to have access to the support of and inspiration provided by the newly formed Russian Chemical Society, which encouraged his continued research on a periodic system, and stimulated him to write textbook-length syntheses of the field, including *The Principles of Chemistry*.[13] It also provided resources to propagate his ideas outside of Russia. The presence of German speakers within this society such as Viktor von Richter, a correspondent of the German Chemical Society, facilitated the circulation and translation of his research within Germany in the 1870s.[13]

1875 proved a watershed year for Mendeleev's table, with the successful prediction of the chemical properties of the newly discovered element gallium. News of his system spread fast, and by the late 1880s, the majority of British and US chemistry textbooks were discussing his periodic law.[12] In 1891, when his periodic system was in its fifth edition in Russia, it was translated into English for the first time.[1] Finally, the discovery of noble gases in the 1890s to 1900s, which initially appeared to contradict his system, ultimately cemented its success: he was able to fit these into the final group in his table.[1,14]

Mendeleev's success was not necessarily a result of him discovering a yet unknown feature of nature. On one level, he created a useful predictive, classificatory and representational system, which provided a record of the past, and a depiction of the present, which also looked towards the future. On another level, he was fortunately positioned within a network of Russian and German chemists, who facilitated the circulation and translation of his work. Ultimately, his system rapidly became the standard depiction of the periodic system, which has constantly been added to and adapted ever since. Since 1869, a cascade of at least 700 representations of the periodic system have been produced, and the flow shows no sign of stopping as new elements are discovered.[15] One recent article published in *Nature* even suggested that it should be turned upside down! Inverting the periodic table, the authors argue, would not only give it 'legs', but offer psychological and pedagogical advantages. In high school classrooms, the bottom area of the table is least often referred to by teachers, but the easiest for desk-bound teenagers to see. Turning it upside down would also apparently be 'consistent with psychological evidence that people associate greater magnitudes (numbers) with higher vertical positions'[16]. With or without 'legs', rotated or not, the periodic table has grounded itself as one of the most influential representations in the history of science, and it seems its stability shows no signs of faltering.

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