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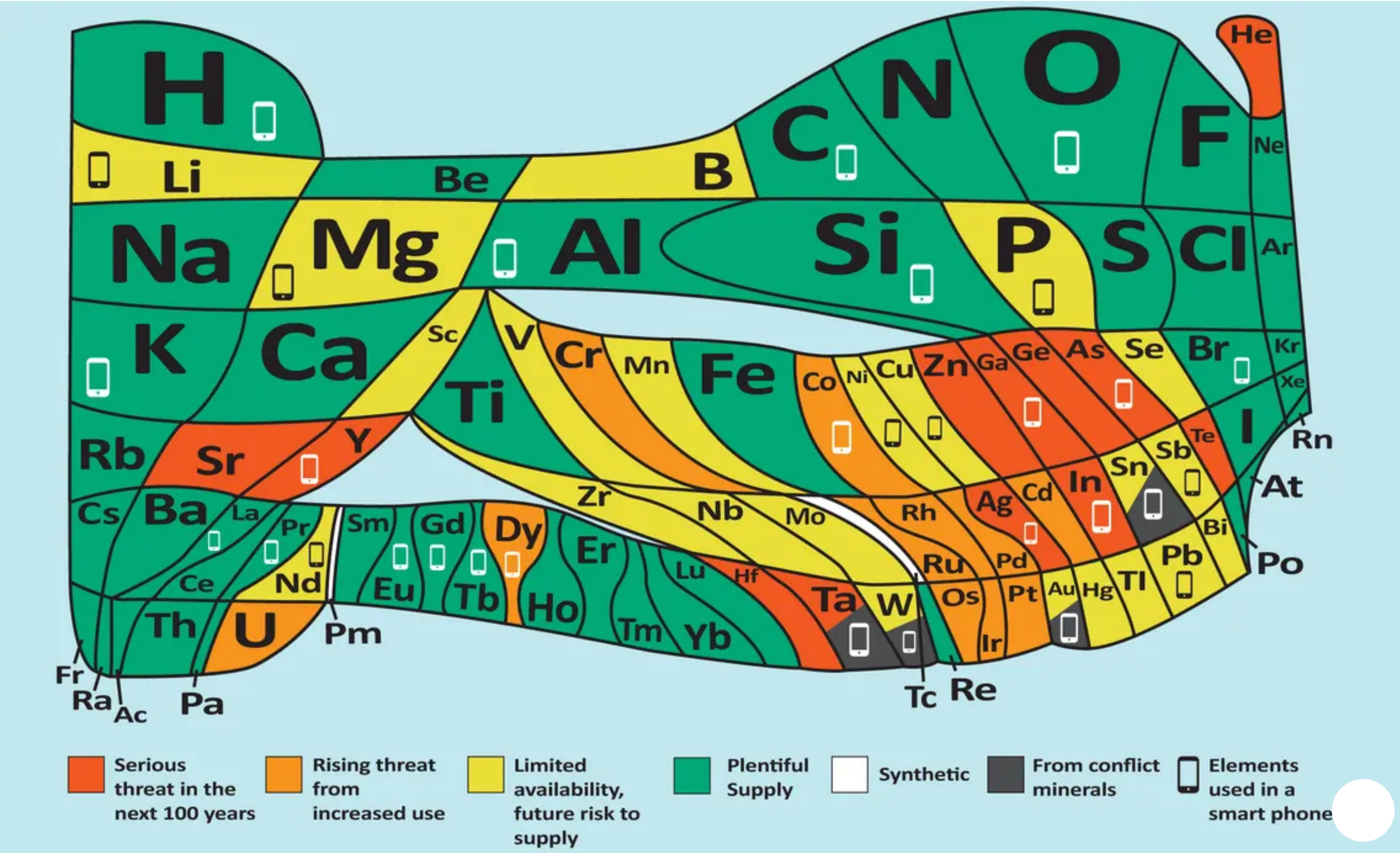

Elemental: the periodic table at 150

endeleev’s chemical grid system defined our world - and the rarer elements it classifies are vital to modern life

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Sat 2 Feb 2019 15.00 GMT

This year marks the 150th anniversary of the publication of the first periodic table. This grid-like arrangement of the elements is probably only familiar to most of us from the tatty poster hanging on the wall of the chemistry classroom at school - only slightly less memorable than the faint background of weird smells in the lab. But when the Russian chemist Dmitri Mendeleev laid out his vision for ordering the chemical world in 1869, it was revolutionary.

This is because the periodic table is far more than just a list of the elements we know. It’s a way of categorising and sorting them: finding the order in the mess of chemical reactions. The startling realisation was that there is a repeating pattern - a periodicity - in the properties of the elements, such as how they react with each other. (We know now that fundamentally this comes down to how the electrons in an atom, which determine how it behaves, fit into successive shells around the nucleus.) The known elements can be laid out into rows and columns, with those lining up in the same column sharing characteristics, like a chemical family. Neon, argon and xenon, for example, all have similar properties: they are the noble gases and are exceedingly reluctant to be cajoled into any reactions. And when electricity is passed through a tubeful, they emit garish colours; the lights that became synonymous with Las Vegas and other urban centres.

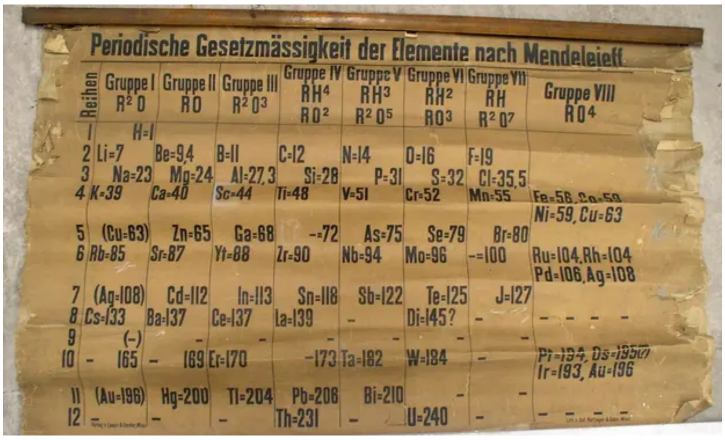
endeleev's flash of insight (he later claimed to have seen his whole grand construct in a dream) also allowed him to infer the existence of as yet undiscovered elements - holes in the brickwork of known elements - and even to predict their properties. He postulated that "ekaaluminium" must exist in the gap in his table immediately below aluminium; we now know this as gallium, and his forecasts on its properties were spot on.

endeleev had only 61 known elements at the time to sort, but by the early years of the 20th century we had identified 85 of these fundamental building blocks of the universe, all falling neatly into place in the framework.

These are all naturally occurring elements, and chemists were able to discover and isolate them by studying a wide variety of different minerals from around the world, like elemental prospectors hunting out new finds. But since the mid-1930s chemists have learned to control nuclear reactions to generate their own elements (in effect, achieving transmutation and the dreams of the alchemists). So far, 24 elements have been artificially crafted; extending the bottom row of the periodic table with new creations. These elements do not exist naturally on Earth - their atomic nuclei are so swollen and unstable that they rapidly undergo radioactive decay or nuclear fission to break down again to other elements. So today, chemistry has progressed beyond merely mapping out the natural landscape of the periodic table to actually adding to it, like Holland's land reclamation projects. The last, element 118, was only formally named in November 2016: oganesson. Scientists are now contemplating a bold prospect: starting a whole new, eighth row of the periodic table and entering completely uncharted territory right at the extremities of the chemical world.

These synthetic elements have no applications - they can only ever be made in absolutely trace amounts, and they rapidly decay - but concern is mounting about the growing scarcity of many exotic elements that have become utterly critical to the workings of our modern world.

For most of the history of civilisation we've exploited a pretty small selection of metals, including copper and tin for bronze-age tools, iron for steel, and lead, gold and silver. Our repertoire has begun to diversify over the past century or so, with the widespread use of aluminium and other new metals. But in the past few decades the number of different metals we wield in our technological society has absolutely exploded. A modern smartphone contains more than 30 different elements. These include carbon and hydrogen in the plastic casing, silicon for the microchip wafers, and copper wiring and gold contacts. But there are also small amounts of a large number of other metals, each exploited for its own particular electronic properties, or for the tiny, powerful magnets used in the speaker and vibration motor. This means that if you own a smartphone, you have in your pocket a substantial fraction of all the stable elements of the periodic table. And it's not just modern electronics that demand a huge diversity of different metals. So too do the high-performance alloys used in the turbines of a power station or aircraft jet engine, or the reaction-accelerating catalysts that we use in industrial chemistry for refining oil, producing plastics or synthesising modern medicinal drugs. Yet most of us have never even heard of many of these critical metals - elements with exotic names like tantalum, yttrium or dysprosium.



Early days: possibly the world's oldest extant copy of Mendeleev's periodic table, found during a clearout at the University of St Andrews in 2014. Photograph: University of St Andrews/PA

The concern is that unlike widespread resources like iron or nitrogen, several of these elements crucial to the modern world may become prohibitively scarce. These have become known as the endangered elements. In response to the Mendeleev anniversary, the European Chemical Society (EuChemS) has released a version of the periodic table (see above) to highlight the elements that are most at risk over the coming decades.

Helium, for example is considered to be under serious threat in the next 100 years. It is the second most abundant element in the universe, but preciously rare on Earth because it is light enough to simply escape from the top of our atmosphere. The helium we do use is effectively mined from deep underground, usually along with natural gas, as it is produced as radiation particles from the decay of elements like uranium. Helium is very useful - as a cooling liquid for the superconducting magnets in hospital MRI scanners, for example, or as an extremely light gas for weather balloons and airships. But once it leaks into the air it is lost for ever, and there are concerns over meeting supply in the future. With this perspective, its frivolous use in party balloons seems almost painfully wasteful.

any of these endangered elements are the sort of exotic metals used in modern electronics, and indeed the supply of 17 elements needed for smartphones may give cause for concern in years to come. Particularly worrying is the fact that many of those facing potential scarcity are exactly the elements we need for the green technologies to replace our reliance on fossil fuels - those used in rechargeable batteries, solar panels, and the powerful magnets within the motors of electric cars or generators in wind turbines. Gallium, for example, is needed for integrated circuits, solar panels, blue LEDs and laser diodes for Blu-ray Discs. Indium is used in everything from TVs to laptops, and in particular the touch-sensitive screens of modern smartphones and tablets. It is estimated that at current usage rates, available indium will be used up in 50 years and will become very expensive to collect and purify.

Except for helium, the problem isn't that these scarce elements actually become lost to the planet, but that they become too expensive to mine or too dispersed to recycle effectively. "Rare earth elements", such as yttrium, dysprosium, neodymium and scandium, are actually relatively plentiful in the Earth's crust but aren't geologically concentrated into rich ores. This means that they can't be extracted economically in many areas of the world. And once they have been manufactured as tiny components within an electronic device, they can be even harder to reclaim and recycle. EuChemS calculates that 10m smartphones are discarded or replaced every month in the EU alone, and so serious action is needed to tackle these challenges of elemental scarcity.

The periodic table is 150 years old, and we need to learn how to protect its more vulnerable constituents.

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