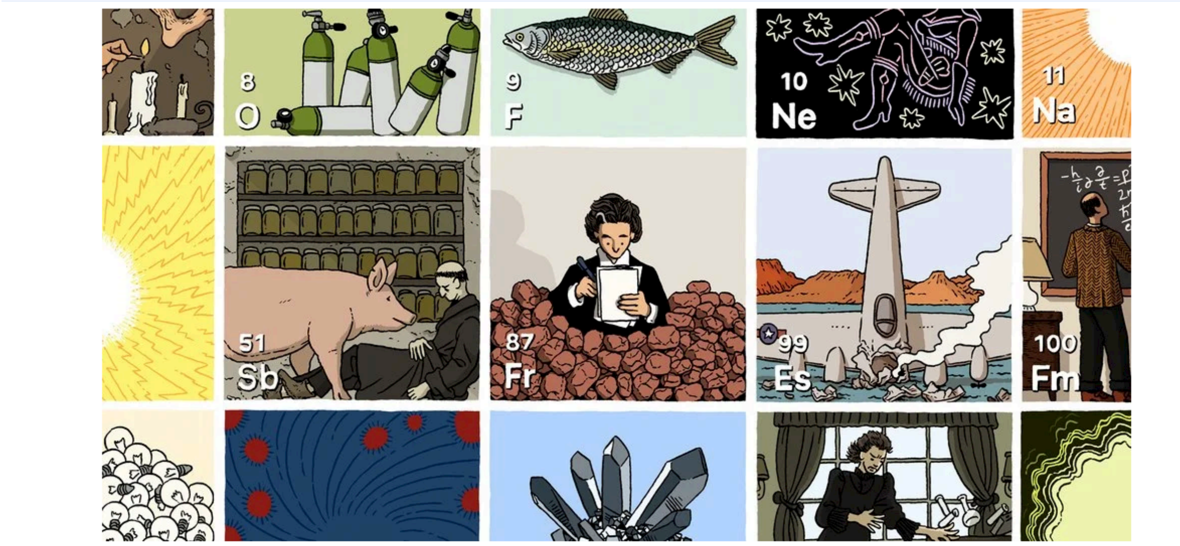

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The Histories Hidden in the Periodic Table

From poisoned monks and nuclear bombs to the "transfermium wars," mapping the atomic world hasn't been easy.

By Neima Jahromi

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Illustration by Ilya Milstein

The story of the fifteenth element began in Hamburg, in 1669. The unsuccessful glassblower and alchemist Hennig Brandt was trying to find the philosopher's stone, a mythical substance that could turn base metals into gold. Instead, he distilled something new. It was foamy and, depending on the preparation, yellow or black. He called it "cold fire," because it glowed in the dark. Interested parties took a look; some felt that they were in the presence of a miracle. "If anyone had rubbed himself all over with it," one observer noted, "his whole figure would have shone, as once did that of Moses when he came down from Mt. Sinai." Robert Boyle, the father of modern chemistry, put some on his hand and noted how "mild and innocent" it seemed. Another scientist saw particles in it twinkling "like little stars."

At first, no one could figure out what the Prometheus of Hamburg had stolen. After one of Brandt's confidants provided a hint—the main ingredient was "somewhat that belong'd to the Body of Man"—Boyle deduced that he and his peers had been smearing themselves with processed urine. As the Cambridge chemist Peter Wothers explains in his new history of the elements, "Antimony, Gold, and Jupiter's Wolf" (Oxford), Brandt's recipe called for a ton of urine. It was left out in buckets long enough to attract maggots, then distilled in hot furnaces, creating a hundred and twenty grams of "cold fire." Brandt believed that, if he could collect enough of this substance, he might be able to create the philosopher's stone. In 1678, the Duke of Saxony asked him to collect a hundred tons of urine from a garrison of soldiers and render it into what Boyle and others soon started to call phosphorus—Latin for "light-bearer."

The soapy phosphorus that Brandt cooked up was a curiosity. But, in England, Boyle began producing it in a purer, more solid form, which turned out to be highly flammable. Another scientist toying with Boyle's phosphorus found that, "if the Privy Parts be therewith rubb'd, they will be inflamed and burning for a good while after." Boyle, for his part, wondered whether it could be harnessed as a starter for gunpowder. (His assistant, the apothecary Ambrose Godfrey, set his head on fire and burned "two or three great holes in his breeches" while investigating the substance.) The phosphorus industry grew throughout the eighteenth century, in part because physicians wrongly believed that it had medicinal value. In the eighteen-hundreds, match producers found that wood splints tipped with phosphorus were less dangerous than their sulfur-coated predecessors; not long afterward, the discovery that electric furnaces could extract phosphorus from ore at a large scale led to the development of explosives. In the Second World War, in what Wothers calls “a tragic twist of fate,” Hamburg, Brandt’s home town, was destroyed by Allied bombers dropping phosphorus munitions.

Wothers finds many such twists in the stories hidden behind the squares of the periodic table. Antimony (element No. 51) is a lustrous mineral; four thousand years ago, people carved vases out of it, and it appears in cosmetic regimes described in the Old Testament. According to an account given by the seventeenth-century apothecary and alchemist Pierre Pomet (offered up by Wothers as possibly apocryphal), antimony got its name from the story of a German monk who fed it to his fellow-brethren. The monk had given some to a few pigs, who vomited at first but then grew healthy and fat. Unfortunately, every monk who ingested it died. “This therefore was the reason of this Mineral being call’d Antimony,” Pomet wrote, “as being destructive of the Monks.” (In a less fatal episode, a nineteenth-century doctor and his friends consumed fifteen milligrams of tellurium each: they had garlic breath for eight months.)

The names of the elements have long been a source of contention and incomprehension. Hydrogen, Wothers points out, is Greek for “water-former,” while oxygen is Greek for “acid-former”; in fact, it’s hydrogen that bonds together with other elements to make acids and oxygen that bonds hydrogen to make water. “Aluminium,” Charles Dickens wrote, in 1856, is “a fossilized part of Latin speech, about as suited to the mouths of the populace as an ichthyosauros cutlet or a dinornis marrow-bone.” (It has its root in the Latin for “bitter salt,” after the clay from which the once-precious metal was derived; Dickens’s suggestions—“loam-silver” and “glebe-gold”—weren’t much better.) The French chemist Marguerite Perey, a protégée of Marie Curie, discovered an element of her own, in 1939. She wanted to call it “catium,” to honor the particle’s strong attraction to cathodes, devices used to send electricity through a chemical substance; Curie’s daughter, Irène Joliot-Curie, worried that English speakers would associate the element with house cats. Perey, being French, decided to call it francium instead.

Many historians date the invention of the periodic table to the publication, a hundred and fifty years ago, of a textbook by the Russian chemist Dmitri I. Mendeleev. But Eric Scerri, the author of “The Periodic Table: Its Story and Its Significance” (Oxford) and a philosopher of chemistry at U.C.L.A.—he studies the history of questions such as “What is an element, really?”—bristles at the notion that Mendeleev revolutionized science when he brought chemical periodicity into clear relief. Periodicity—the idea that larger atoms chime with smaller atoms in a regular way, like notes on a keyboard—didn’t emerge as a bolt from the blue, Scerri argues. It came into focus through the work of a host of scientists; as it did so, ideas that by then were long disdained, such as alchemy, turned out to be right in some respects, and essentially wrong ideas, such as the irreducibility of the elements, turned out to be productive ways of thinking, anyway. Some of the eighteenth- and nineteenth-century chemists who began to notice patterns among certain elements were actually retracing the paths of ancient Greek atomists such as Democritus and Leucippus, who, in the fifth century B.C., had argued that invisible and indivisible particles made up everything we could see and touch. The atomists believed that those particles were myriad in shape and size, and that their perceptible properties came from the structures they formed when they hooked together.

By the Middle Ages, atomistic ideas had been mostly eclipsed by Aristotle’s theory that four principal elements—fire, earth, water, and air—combined to form the various objects in the universe. But atomism never went away completely. Renaissance scholars believed in a wide variety of elemental schemes. Wothers’s book reprints some of the diagrams that mixed these ideas in advance of the periodic table: a seventeenth-century engraving of the “seven metals” shows seven Roman gods brandishing ancient chemical symbols (the deities reminded viewers that iron was from Mars and copper from Venus); another shows the seven metals and Aristotle’s four elements in a triangular arrangement. Ringing the whole diagram is a Latin motto: “Although I am invisible, I am nonetheless the father and mother of all visible earthly bodies.”

You didn’t have to be a scholar, of course, to believe in a world made up of more than four elements. Seventeenth-century miners, Wothers writes, distinguished between different kinds of air: they called the lighter air that swirled at the top of caves “fire-damp,” because it easily burst into flames, and the heavy clouds that hung near the ground “choke-damp,” because they made it hard to breathe. In the eighteenth century, locals dubbed a cave near Naples the *Grotta del Cane*: dogs who wandered into the cave, unable to raise their heads above the gas seeping out of the Earth, soon began to choke to death; once returned to the open air, the animals would revive.

As these observations proliferated, so did the conviction that there must be many different elements. By the end of the eighteenth century, scientists, combining substances, began realizing that certain materials always reacted in the same proportions, which suggested that they had different underlying masses. (It always seemed to take a little more ammonia than it did magnesia to neutralize the same amount of sulfuric acid.) In 1803, the English scientist John Dalton proposed that atoms were at work in such reactions; he encouraged his peers to help him determine how much these invisible entities weighed. What Scerri calls a “craze for searching for numerical regularities” began. Chemists soon noticed patterns when they grouped elements into sets of three by atomic weight. (Lithium, sodium, and potassium, for example, all fizz or explode in water; it turned out that sodium’s atomic weight is the average of lithium’s and potassium’s.) Such experiments offered glimpses of an order within the elemental universe. But the work was frustrating. In 1836, the chemist Jean Baptiste André Dumas, a disciple of Dalton, threw up his hands in despair. “What remains of the ambitious excursion we allowed ourselves into the domain of atoms?” he wrote. “If I were master I would erase the word ‘atom’ from the science.”

Other chemists pressed on. As atomic weights grew more accurate, more patterns emerged. In 1864, the German chemist Julius Lothar Meyer published a table of twenty-eight elements. Meyer’s elements, arranged mostly by increasing weight, were also lined up according to their common chemical properties, which repeated at regular intervals. Five years later, Mendeleev published his own periodic table, which steadily evolved into the version we use today. Like Meyer, Mendeleev had organized his particles into a rough grid, its rows containing elements with similar properties. But he also garnished his table with many tempting question marks and empty spaces, and made explicit elemental prophecies. Mendeleev accurately predicted the existence of then-undiscovered elements, such as gallium and germanium, and foretold their interactions with other elements.

Mendeleev’s predictions were wrong as often as they were right. But, Scerri explains, the Russian chemist was a master storyteller and, compared to Meyer and other competitors, a more effective evangelist for the periodic system. Mendeleev took every opportunity to argue, at times heedlessly, that the characteristics of the elements repeat in an orderly and predictable way. He was both indefatigable and inflexible, at least until the tide of scientific opinion turned against him. In the late eighteen-fifties, scientists found that the elemental makeup of a given substance could be deduced from the light that it gave off when set ablaze; in 1868, a French astronomer, Jules Janssen, used the technique to discover helium (element No. 2) on the surface of the sun, during a total solar eclipse. At first, Mendeleev argued that helium could not exist; it had no place on the periodic table. But, around the turn of the twentieth century, after the other noble gases had been discovered and shown to share properties with helium, other scientists made a column just for them, and Mendeleev fell in line. (The column runs along the right, with helium poking out on top.)

The table’s ability to adapt has helped it endure. In the twentieth century, scientists realized that periodicity wasn’t determined by atomic weight; instead, what mattered was the number of protons that each atom contained in its nucleus. But this discovery didn’t break the table, either; after a few reshufflings, it became more accurate. Over the past century and a half, our ideas about the universe have changed drastically. But the basic format of the periodic table has endured.

That’s not to say that no one has tried to revise it: Scerri notes that, since the eighteen-sixties, more than a thousand alternative periodic tables have been proposed, often with the aim of capturing periodic patterns left out of the original. They include Fernando Dufour’s threedimensional Christmas tree, from 1990; Theodor Benfey's spiral pattern, resembling a duck's head, from 1964; and William Crookes's nineteenth-century pretzel-shaped sculpture, which now sits at the Science Museum, in London. This last model placed uranium at its base, under the assumption that chemistry would never encounter a bigger atom. But the elemental ceiling has continued to rise. The stories of the thirty or so elements discovered in the past century—some of which Mendeleev and Meyer couldn't have imagined—constitute the bulk of "Superheavy: Making and Breaking the Periodic Table" (Bloomsbury), by the science journalist Kit Chapman.

Early element hunters had used fire to distill their elements, or else mixed minerals with boiling acid. Those techniques were replaced, in the twentieth century, by technologies that used electricity to shake atoms into pieces. Scientists, moreover, realized that atoms have structures, made up of protons, neutrons, and electrons; those structures can fall apart or get bigger. These developments fundamentally changed our relationship to matter. Discovering an element used to be like finding Dr. Livingstone in East Africa: you knew he was there somewhere. Now the line between discovering and creating blurred. Elements made in the lab might exist nowhere else.

The modern element-hunting era began in the nineteen-thirties, when the physicist Ernest Lawrence directed scientists at the University of California, Berkeley, to develop a series of devices, called cyclotrons, that use electricity to blast protons into foil targets installed inside metal chambers. Researchers soon found that some of the supercharged nuclear particles would glom on to the atoms in the targets and create bigger, heavier elements. The particles were infinitesimally small and their chances of collision were negligible. "It is like shooting birds in the dark in a country where there are only a few birds," Albert Einstein said, in 1934. Still, Lawrence's cyclotrons allowed element hunters to take trillions of shots, and by 1937 one of his devices had created technetium (element No. 43), an atom predicted by Mendeleev. Like all elements first born in cyclotrons, technetium was radioactive. Lawrence won a Nobel Prize for his invention in 1939; that same year, Einstein told President Roosevelt to get working on a nuclear weapon.

Such bombs, when they detonated, further filled out the periodic table. Starting in 1952, the United States blew up hydrogen bombs around the Marshall Islands. Researchers then sent F-84 fighter pilots flying into the explosions. (The fireballs, Chapman notes, were hot enough to "mimic the intense furnace of the Sun.") Scientists had outfitted the wingtips of the F-84s with filters capable of picking up atoms forged in the blast. Bursting through the stems of the mushroom clouds, trying to keep their planes from rattling apart, the pilots, Champan writes, collected "elements usually only present in merging neutron stars." (One pilot, Jimmy Robinson, escaped from the nuclear dust storm to find that his engines had stalled; he died in an attempted water landing.) Later, in a Berkeley laboratory, the physicist Glenn Seaborg and his colleagues detected two hundred atoms of what would become element No. 99 in a filter pulled from one of the planes. It took years of wrangling to declassify their discovery, but the Berkeley scientists publicly described the element in 1954. They drank "an abundance of cocktails" and eventually named their new particle einsteinium, after the man who had suggested the bomb.

Even in laboratory settings, the hunt for new elements could be dangerous. In 1959, Al Ghiorso, a Berkeley physicist with nerves of steel—he was known to fill tennis balls with radioactive material and bat them around—was looking for element No. 102. One day, around lunchtime, he overloaded a particle accelerator with helium while bombarding a filter made of curium; the helium swelled the curium filter, Chapman writes, until it popped like "a balloon filled with radioactive glitter." Ghiorso ducked beneath the cloud, and the building was evacuated. And yet, for his trouble, Ghiorso may not have been the first to discover the element. A Swedish team, using rudimentary equipment, claimed to have found it first; they wanted to call it nobelium, after the Swedish inventor of dynamite. Soviet scientists, meanwhile, questioned the results coming from both Stockholm and Berkeley. The naming of elements No. 100 and No. 101, fermium and mendelevium, had caused little stir, but that relative calm soon shattered. In a period now called the "transfermium wars," the cycle of discovery and doubt became the leitmotif of Cold War element research. (In the end, the International Union of Pure and Applied Chemistry credited the Soviets with the discovery, while allowing the name “nobelium” to stand.) By 1970, there were at least two major variations on the periodic table. Americans named element No. 104 after Ernest Rutherford, the father of nuclear science; the Soviets named it after Igor Kurchatov, the father of Russian nukes.

As the transfermium wars continued, an irony emerged: atomic researchers were chasing immortality through the discovery of elements that quickly blinked out of existence. The “superheavy” particles took massive amounts of energy to produce; they then tended to fall apart, turning into lighter elements, often within nanoseconds. Scientists in the United States and the Soviet Union began trying to figure out how to make them last longer. Experimenting with elements created by the Manhattan Project, researchers realized that they could create two different versions, or isotopes, of promethium, the sixty-first atom on the periodic table. One promethium isotope, with eighty-eight neutrons, has a half-life of a few days; the other, with eighty-six neutrons, has a half-life of a few years. Apparently, the right, “magic” number of neutrons and protons could hold the hypercharged whole of a superheavy element together. Researchers began to wonder if these longer-lasting giant atoms might occur in nature. Chapman presents one scientist’s sketch, from 1978, titled “Map of the Isotopes.” It shows a “sea of instability,” into which a peninsula extends. On the end of the peninsula, a small figure rests within a giant slingshot; the slingshot is aimed toward a “Magic Island,” guarded by a formidable bird of “nuclear viscosity,” with outspread wings.

The dream of a magical island of stable atoms, hidden many rows down the periodic table, set off what Chapman calls a superheavy “gold rush.” Instead of creating superheavy elements, in particle accelerators, researchers began looking for them out in the world. One theory was that, if stable superheavy elements existed, they would be easier to detect farther away from the surface of the Earth, which is bombarded by radioactive cosmic rays that can overwhelm sensitive detectors. Another theory was that superheavy elements (or evidence of them) might be found inside materials made of elements in the same periodic column. Scientists travelled deep into the ocean, dug around salt mines, scrutinized gold nuggets, sent up high-altitude observational balloons, hiked through subway tunnels, scooped brine from the Caspian Sea, picked at sixty-million-year-old shark teeth, and entered cathedrals to analyze stained-glass windows. (The lead lining, they hoped, might have preserved evidence of some ancient nuclear reaction.) But, after two decades of searching, no new superheavy elements were discovered in nature. It seemed to be particle accelerators or nothing.

In recent years, instead of discovering an island of stability, scientists may have nearly done the opposite: they’ve created superheavy elements that threaten to break the periodic table. In 1998, Russian scientists created a new element that blinked out of existence after little more than a second. The head Russian element hunter, Yuri Oganessian, named it after his late mentor, Georgy Flerov. In 2016, Oganessian got his name on an atom, too. His element, which is currently the last one on the periodic table, was likewise a blip in the machine. Chapman believes that elements like flerovium and oganesson (elements No. 114 and No. 118, respectively) might spell the “end of chemistry as we know it.” Oganesson sits at the bottom of the column with the noble gases, but a paper from 2017 suggests that it may not belong there: the velocities of its supercharged electrons likely approach the speed of light, and so the element may not act like the gases with which it’s grouped. Instead, oganesson and its neighbors might follow the rules of relativity; time and space might appear to bend inside them, and their properties could follow suit.

Scerri doesn’t believe the periodic table is seriously threatened by elements like oganesson; he points out that some of the electrons in gold atoms spin at velocities that approach light speed, too. It could be that even relativity fits a pattern—“a further testament,” he writes, “to the underlying fundamental nature of the periodic law.” (Copernicium, No. 112, is a row below gold, and also seems to incorporate relativistic effects.) And yet Scerri argues that such elements destabilize the periodic table in a different way. The table was originally imagined as describing the building blocks of nature. But, as element hunters have become element makers, the table’s meaning has changed. It now describes what is possible, as well as what merely exists.

Even if there is an island of atomic stability, the superheavy elements that live on it are likely to be exceedingly rare. Hydrogen atoms burning up in a single star only tend to get as heavy as iron (element No. 26 of the hundred and seventy-two or hundred and seventy-three possible elements some scientists conjecture could exist). Astrophysicists believe that the bigger atoms which arise in collapsing stars might, after travelling vast distances in space, land in the cauldrons of other suns and keep growing. But the Earth is four and a half billion years old—much older than the half-life of even the most stable predicted superheavy elements—and few traces of them have been found here. (Because superheavy elements are likely to decay quickly, element hunters examine meteorites, which may have issued from more recent stellar explosions.) In the next few years, atomic scientists with particle accelerators will easily create elements No. 119 and No. 120. Those elements may never be seen outside of the lab.

Elemental fever seems to have cooled off in the United States, but it continues to simmer elsewhere. Japan discovered its first element, nihonium, No. 113, in 2004, and Chapman reports that Japanese children read mangas dramatizing the work of the country's top nuclear physicist, Kosuke Morita. When nihonium was officially added to the periodic table, in 2016, Crown Prince Naruhito was deeply moved: at a special ceremony, he reminisced about copying the periodic table by hand as a boy. Meanwhile, in Geneva, scientists at *CERN* have broadened the hunt to other parts of the cosmos. "Some people believe that there could be different forms of dark matter," Ying Wun Yvonne Ng, a particle-physics researcher, told me. "Who knows," she said. "It could potentially fill up a much larger periodic table."

Technetium, the first man-made element, is still used in cancer treatments around the world. In theory, newer elements could be similarly useful: according to Chapman, scientists have speculated that a pea-size sample of flerovium "could power a city," if it could be stabilized. In truth, though, it seems that obsessive element hunters are in it for abstract reasons that transcend even scientific glory. In "Superheavy," Chapman visits Oganessian at his lab in Russia to ask him why he's still hunting—especially now that he has an element that bears his name. "If you have a device that can do this," Oganessian replies, "why not?" You build the machine to find the atoms; you make the atoms because you have the machine. "This is like Pandora's box," Oganessian says, patting a component of a cyclotron that's currently under construction. "A new facility. A new accelerator." Keep finding elements, and the story never has to end.

- *Neima Jahromi is a member of The New Yorker's editorial staff.*