

## 7 ELEMENTAL MATTERS

CHEMISTRY AS AN earnest and respectable science is often said to date from 1661, when Robert Boyle of Oxford published *The Sceptical Chymist*—the first work to distinguish between chemists and alchemists—but it was a slow and often erratic transition. Into the eighteenth century scholars could feel oddly comfortable in both camps—like the German Johann Becher, who produced an unexceptionable work on mineralogy called *Physica Subterranea*, but who also was certain that, given the right materials, he could make himself invisible.

Perhaps nothing better typifies the strange and often accidental nature of chemical science in its early days than a discovery made by a German named Hennig Brand in 1675. Brand became convinced that gold could somehow be distilled from human urine. (The similarity of color seems to have been a factor in his conclusion.) He assembled fifty buckets of human urine, which he kept for months in his cellar. By various recondite processes, he converted the urine first into a noxious paste and then into a translucent waxy substance. None of it yielded gold, of course, but a strange and interesting thing did happen. After a time, the substance began to glow. Moreover, when exposed to air, it often spontaneously burst into flame.

The commercial potential for the stuff—which soon became known as phosphorus, from Greek and Latin roots meaning “light bearing”—was not lost on eager businesspeople, but the difficulties of manufacture made it too costly to exploit. An ounce of phosphorus retailed for six guineas—perhaps five hundred dollars in today’s money—or more than gold.

At first, soldiers were called on to provide the raw material, but such an arrangement was hardly conducive to industrial-scale production. In the 1750s a Swedish chemist named Karl (or Carl) Scheele devised a way to manufacture phosphorus in bulk without the slop or smell of urine. It was largely because of this mastery of phosphorus that Sweden became, and remains, a leading producer of matches.

Scheele was both an extraordinary and extraordinarily luckless fellow. A poor pharmacist with little in the way of advanced apparatus, he discovered eight elements—chlorine, fluorine, manganese, barium, molybdenum, tungsten, nitrogen, and oxygen—and got credit for none of them. In every case, his finds were either overlooked or made it into publication after someone else had made the same discovery independently. He also discovered many useful compounds, among them ammonia, glycerin, and tannic acid, and was the first to see the commercial potential of chlorine as a bleach—all breakthroughs that made other people extremely wealthy.

Scheele’s one notable shortcoming was a curious insistence on tasting a little of everything he worked with, including such notoriously disagreeable substances as mercury, prussic acid (another of his discoveries), and hydrocyanic acid—a compound so famously poisonous that 150 years later Erwin Schrödinger chose it as his toxin of choice in a famous thought experiment (see page 146). Scheele’s rashness eventually caught up with him. In 1786, aged just forty-three, he was found dead at his workbench surrounded by an array of toxic chemicals, any one of which could have accounted for the stunned and terminal look on his face.

Were the world just and Swedish-speaking, Scheele would have enjoyed universal acclaim. Instead credit has tended to lodge with more celebrated chemists, mostly from the English-speaking world. Scheele discovered oxygen in 1772, but for various heartbreakingly

complicated reasons could not get his paper published in a timely manner. Instead credit went to Joseph Priestley, who discovered the same element independently, but latterly, in the summer of 1774. Even more remarkable was Scheele's failure to receive credit for the discovery of chlorine. Nearly all textbooks still attribute chlorine's discovery to Humphry Davy, who did indeed find it, but thirty-six *years* after Scheele had.

Although chemistry had come a long way in the century that separated Newton and Boyle from Scheele and Priestley and Henry Cavendish, it still had a long way to go. Right up to the closing years of the eighteenth century (and in Priestley's case a little beyond) scientists everywhere searched for, and sometimes believed they had actually found, things that just weren't there: vitiated airs, dephlogisticated marine acids, phloxes, calxes, terraqueous exhalations, and, above all, phlogiston, the substance that was thought to be the active agent in combustion. Somewhere in all this, it was thought, there also resided a mysterious *élan vital*, the force that brought inanimate objects to life. No one knew where this ethereal essence lay, but two things seemed probable: that you could enliven it with a jolt of electricity (a notion Mary Shelley exploited to full effect in her novel *Frankenstein*) and that it existed in some substances but not others, which is why we ended up with two branches of chemistry: organic (for those substances that were thought to have it) and inorganic (for those that did not).

Someone of insight was needed to thrust chemistry into the modern age, and it was the French who provided him. His name was Antoine-Laurent Lavoisier. Born in 1743, Lavoisier was a member of the minor nobility (his father had purchased a title for the family). In 1768, he bought a practicing share in a deeply despised institution called the Ferme Générale (or General Farm), which collected taxes and fees on behalf of the government. Although Lavoisier himself was by all accounts mild and fair-minded, the company he worked for was neither. For one thing, it did not tax the rich but only the poor, and then often arbitrarily. For Lavoisier, the appeal of the institution was that it provided him with the wealth to follow his principal devotion, science. At his peak, his personal earnings reached 150,000 livres a year—perhaps \$20 million in today's money.

Three years after embarking on this lucrative career path, he married the fourteen-year-old daughter of one of his bosses. The marriage was a meeting of hearts and minds both. Madame Lavoisier had an incisive intellect and soon was working productively alongside her husband. Despite the demands of his job and busy social life, they managed to put in five hours of science on most days—two in the early morning and three in the evening—as well as the whole of Sunday, which they called their *jour de bonheur* (day of happiness). Somehow Lavoisier also found the time to be commissioner of gunpowder, supervise the building of a wall around Paris to deter smugglers, help found the metric system, and coauthor the handbook *Méthode de Nomenclature Chimique*, which became the bible for agreeing on the names of the elements.

As a leading member of the Académie Royale des Sciences, he was also required to take an informed and active interest in whatever was topical—hypnotism, prison reform, the respiration of insects, the water supply of Paris. It was in such a capacity in 1780 that Lavoisier made some dismissive remarks about a new theory of combustion that had been submitted to the academy by a hopeful young scientist. The theory was indeed wrong, but the scientist never forgave him. His name was Jean-Paul Marat.

The one thing Lavoisier never did was discover an element. At a time when it seemed as if almost anybody with a beaker, a flame, and some interesting powders could discover

something new—and when, not incidentally, some two-thirds of the elements were yet to be found—Lavoisier failed to uncover a single one. It certainly wasn't for want of beakers. Lavoisier had thirteen thousand of them in what was, to an almost preposterous degree, the finest private laboratory in existence.

Instead he took the discoveries of others and made sense of them. He threw out phlogiston and mephitic airs. He identified oxygen and hydrogen for what they were and gave them both their modern names. In short, he helped to bring rigor, clarity, and method to chemistry.

And his fancy equipment did in fact come in very handy. For years, he and Madame Lavoisier occupied themselves with extremely exacting studies requiring the finest measurements. They determined, for instance, that a rusting object doesn't lose weight, as everyone had long assumed, but gains weight—an extraordinary discovery. Somehow as it rusted the object was attracting elemental particles from the air. It was the first realization that matter can be transformed but not eliminated. If you burned this book now, its matter would be changed to ash and smoke, but the net amount of stuff in the universe would be the same. This became known as the conservation of mass, and it was a revolutionary concept. Unfortunately, it coincided with another type of revolution—the French one—and for this one Lavoisier was entirely on the wrong side.

Not only was he a member of the hated Ferme Générale, but he had enthusiastically built the wall that enclosed Paris—an edifice so loathed that it was the first thing attacked by the rebellious citizens. Capitalizing on this, in 1791 Marat, now a leading voice in the National Assembly, denounced Lavoisier and suggested that it was well past time for his hanging. Soon afterward the Ferme Générale was shut down. Not long after this Marat was murdered in his bath by an aggrieved young woman named Charlotte Corday, but by this time it was too late for Lavoisier.

In 1793, the Reign of Terror, already intense, ratcheted up to a higher gear. In October Marie Antoinette was sent to the guillotine. The following month, as Lavoisier and his wife were making tardy plans to slip away to Scotland, Lavoisier was arrested. In May he and thirty-one fellow farmers-general were brought before the Revolutionary Tribunal (in a courtroom presided over by a bust of Marat). Eight were granted acquittals, but Lavoisier and the others were taken directly to the Place de la Revolution (now the Place de la Concorde), site of the busiest of French guillotines. Lavoisier watched his father-in-law beheaded, then stepped up and accepted his fate. Less than three months later, on July 27, Robespierre himself was dispatched in the same way and in the same place, and the Reign of Terror swiftly ended.

A hundred years after his death, a statue of Lavoisier was erected in Paris and much admired until someone pointed out that it looked nothing like him. Under questioning the sculptor admitted that he had used the head of the mathematician and philosopher the Marquis de Condorcet—apparently he had a spare—in the hope that no one would notice or, having noticed, would care. In the second regard he was correct. The statue of Lavoisier-cum-Condorcet was allowed to remain in place for another half century until the Second World War when, one morning, it was taken away and melted down for scrap.

In the early 1800s there arose in England a fashion for inhaling nitrous oxide, or laughing gas, after it was discovered that its use “was attended by a highly pleasurable thrilling.” For

the next half century it would be the drug of choice for young people. One learned body, the Askesian Society, was for a time devoted to little else. Theaters put on “laughing gas evenings” where volunteers could refresh themselves with a robust inhalation and then entertain the audience with their comical staggerings.

It wasn't until 1846 that anyone got around to finding a practical use for nitrous oxide, as an anesthetic. Goodness knows how many tens of thousands of people suffered unnecessary agonies under the surgeon's knife because no one thought of the gas's most obvious practical application.

I mention this to make the point that chemistry, having come so far in the eighteenth century, rather lost its bearings in the first decades of the nineteenth, in much the way that geology would in the early years of the twentieth. Partly it was to do with the limitations of equipment—there were, for instance, no centrifuges until the second half of the century, severely restricting many kinds of experiments—and partly it was social. Chemistry was, generally speaking, a science for businesspeople, for those who worked with coal and potash and dyes, and not gentlemen, who tended to be drawn to geology, natural history, and physics. (This was slightly less true in continental Europe than in Britain, but only slightly.) It is perhaps telling that one of the most important observations of the century, Brownian motion, which established the active nature of molecules, was made not by a chemist but by a Scottish botanist, Robert Brown. (What Brown noticed, in 1827, was that tiny grains of pollen suspended in water remained indefinitely in motion no matter how long he gave them to settle. The cause of this perpetual motion—namely the actions of invisible molecules—was long a mystery.)

Things might have been worse had it not been for a splendidly improbable character named Count von Rumford, who, despite the grandeur of his title, began life in Woburn, Massachusetts, in 1753 as plain Benjamin Thompson. Thompson was dashing and ambitious, “handsome in feature and figure,” occasionally courageous and exceedingly bright, but untroubled by anything so inconveniencing as a scruple. At nineteen he married a rich widow fourteen years his senior, but at the outbreak of revolution in the colonies he unwisely sided with the loyalists, for a time spying on their behalf. In the fateful year of 1776, facing arrest “for lukewarmness in the cause of liberty,” he abandoned his wife and child and fled just ahead of a mob of anti-Royalists armed with buckets of hot tar, bags of feathers, and an earnest desire to adorn him with both.

He decamped first to England and then to Germany, where he served as a military advisor to the government of Bavaria, so impressing the authorities that in 1791 he was named Count von Rumford of the Holy Roman Empire. While in Munich, he also designed and laid out the famous park known as the English Garden.

In between these undertakings, he somehow found time to conduct a good deal of solid science. He became the world's foremost authority on thermodynamics and the first to elucidate the principles of the convection of fluids and the circulation of ocean currents. He also invented several useful objects, including a drip coffeemaker, thermal underwear, and a type of range still known as the Rumford fireplace. In 1805, during a sojourn in France, he wooed and married Madame Lavoisier, widow of Antoine-Laurent. The marriage was not a success and they soon parted. Rumford stayed on in France, where he died, universally esteemed by all but his former wives, in 1814.

But our purpose in mentioning him here is that in 1799, during a comparatively brief interlude in London, he founded the Royal Institution, yet another of the many learned societies that popped into being all over Britain in the late eighteenth and early nineteenth centuries. For a time it was almost the only institution of standing to actively promote the young science of chemistry, and that was thanks almost entirely to a brilliant young man named Humphry Davy, who was appointed the institution's professor of chemistry shortly after its inception and rapidly gained fame as an outstanding lecturer and productive experimentalist.

Soon after taking up his position, Davy began to bang out new elements one after another—potassium, sodium, magnesium, calcium, strontium, and aluminum or aluminium, depending on which branch of English you favor.<sup>1</sup> He discovered so many elements not so much because he was serially astute as because he developed an ingenious technique of applying electricity to a molten substance—electrolysis, as it is known. Altogether he discovered a dozen elements, a fifth of the known total of his day. Davy might have done far more, but unfortunately as a young man he developed an abiding attachment to the buoyant pleasures of nitrous oxide. He grew so attached to the gas that he drew on it (literally) three or four times a day. Eventually, in 1829, it is thought to have killed him.

Fortunately more sober types were at work elsewhere. In 1808, a dour Quaker named John Dalton became the first person to intimate the nature of an atom (progress that will be discussed more completely a little further on), and in 1811 an Italian with the splendidly operatic name of Lorenzo Romano Amadeo Carlo Avogadro, Count of Quarequa and Cerreto, made a discovery that would prove highly significant in the long term—namely, that two equal volumes of gases of any type, if kept at the same pressure and temperature, will contain identical numbers of molecules.

Two things were notable about Avogadro's Principle, as it became known. First, it provided a basis for more accurately measuring the size and weight of atoms. Using Avogadro's mathematics, chemists were eventually able to work out, for instance, that a typical atom had a diameter of 0.00000008 centimeters, which is very little indeed. And second, almost no one knew about Avogadro's appealingly simple principle for almost fifty years.<sup>2</sup>

Partly this was because Avogadro himself was a retiring fellow—he worked alone, corresponded very little with fellow scientists, published few papers, and attended no meetings—but also it was because there were no meetings to attend and few chemical journals in which to publish. This is a fairly extraordinary fact. The Industrial Revolution was

---

<sup>1</sup> The confusion over the aluminum/aluminium spelling arose because of some uncharacteristic indecisiveness on Davy's part. When he first isolated the element in 1808, he called it *aluminium*. For some reason he thought better of that and changed it to *aluminum* four years later. Americans dutifully adopted the new term, but many British users disliked *aluminum*, pointing out that it disrupted the -ium pattern established by sodium, calcium, and strontium, so they added a vowel and syllable.

<sup>2</sup> The principle led to the much later adoption of Avogadro's number, a basic unit of measure in chemistry, which was named for Avogadro long after his death. It is the number of molecules found in 2.016 grams of hydrogen gas (or an equal volume of any other gas). Its value is placed at  $6.0221367 \times 10^{23}$ , which is an enormously large number. Chemistry students have long amused themselves by computing just how large a number it is, so I can report that it is equivalent to the number of popcorn kernels needed to cover the United States to a depth of nine miles, or cupfuls of water in the Pacific Ocean, or soft drink cans that would, evenly stacked, cover the Earth to a depth of 200 miles. An equivalent number of American pennies would be enough to make every person on Earth a dollar trillionaire. It is a big number.

driven in large part by developments in chemistry, and yet as an organized science chemistry barely existed for decades.

The Chemical Society of London was not founded until 1841 and didn't begin to produce a regular journal until 1848, by which time most learned societies in Britain—Geological, Geographical, Zoological, Horticultural, and Linnaean (for naturalists and botanists)—were at least twenty years old and often much more. The rival Institute of Chemistry didn't come into being until 1877, a year after the founding of the American Chemical Society. Because chemistry was so slow to get organized, news of Avogadro's important breakthrough of 1811 didn't begin to become general until the first international chemistry congress, in Karlsruhe, in 1860.

Because chemists for so long worked in isolation, conventions were slow to emerge. Until well into the second half of the century, the formula  $H_2O_2$  might mean water to one chemist but hydrogen peroxide to another.  $C_2H_4$  could signify ethylene or marsh gas. There was hardly a molecule that was uniformly represented everywhere.

Chemists also used a bewildering variety of symbols and abbreviations, often self-invented. Sweden's J. J. Berzelius brought a much-needed measure of order to matters by decreeing that the elements be abbreviated on the basis of their Greek or Latin names, which is why the abbreviation for iron is Fe (from the Latin *ferrum*) and that for silver is Ag (from the Latin *argentum*). That so many of the other abbreviations accord with their English names (N for nitrogen, O for Oxygen, H for hydrogen, and so on) reflects English's Latinate nature, not its exalted status. To indicate the number of atoms in a molecule, Berzelius employed a superscript notation, as in  $H^2O$ . Later, for no special reason, the fashion became to render the number as subscript:  $H_2O$ .

Despite the occasional tidying-up, chemistry by the second half of the nineteenth century was in something of a mess, which is why everybody was so pleased by the rise to prominence in 1869 of an odd and crazed-looking professor at the University of St. Petersburg named Dmitri Ivanovich Mendeleev.

Mendeleev (also sometimes spelled Mendeleev or Mendeléeef) was born in 1834 at Tobolsk, in the far west of Siberia, into a well-educated, reasonably prosperous, and very large family—so large, in fact, that history has lost track of exactly how many Mendeleevs there were: some sources say there were fourteen children, some say seventeen. All agree, at any rate, that Dmitri was the youngest. Luck was not always with the Mendeleevs. When Dmitri was small his father, the headmaster of a local school, went blind and his mother had to go out to work. Clearly an extraordinary woman, she eventually became the manager of a successful glass factory. All went well until 1848, when the factory burned down and the family was reduced to penury. Determined to get her youngest child an education, the indomitable Mrs. Mendeleev hitchhiked with young Dmitri four thousand miles to St. Petersburg—that's equivalent to traveling from London to Equatorial Guinea—and deposited him at the Institute of Pedagogy. Worn out by her efforts, she died soon after.

Mendeleev dutifully completed his studies and eventually landed a position at the local university. There he was a competent but not terribly outstanding chemist, known more for his wild hair and beard, which he had trimmed just once a year, than for his gifts in the laboratory.

However, in 1869, at the age of thirty-five, he began to toy with a way to arrange the elements. At the time, elements were normally grouped in two ways—either by atomic weight (using Avogadro's Principle) or by common properties (whether they were metals or gases, for instance). Mendeleev's breakthrough was to see that the two could be combined in a single table.

As is often the way in science, the principle had actually been anticipated three years previously by an amateur chemist in England named John Newlands. He suggested that when elements were arranged by weight they appeared to repeat certain properties—in a sense to harmonize—at every eighth place along the scale. Slightly unwisely, for this was an idea whose time had not quite yet come, Newlands called it the Law of Octaves and likened the arrangement to the octaves on a piano keyboard. Perhaps there was something in Newlands's manner of presentation, but the idea was considered fundamentally preposterous and widely mocked. At gatherings, droll members of the audience would sometimes ask him if he could get his elements to play them a little tune. Discouraged, Newlands gave up pushing the idea and soon dropped from view altogether.

Mendeleev used a slightly different approach, placing his elements into groups of seven, but employed fundamentally the same principle. Suddenly the idea seemed brilliant and wondrously perceptive. Because the properties repeated themselves periodically, the invention became known as the periodic table.

Mendeleev was said to have been inspired by the card game known as solitaire in North America and patience elsewhere, wherein cards are arranged by suit horizontally and by number vertically. Using a broadly similar concept, he arranged the elements in horizontal rows called periods and vertical columns called groups. This instantly showed one set of relationships when read up and down and another when read from side to side. Specifically, the vertical columns put together chemicals that have similar properties. Thus copper sits on top of silver and silver sits on top of gold because of their chemical affinities as metals, while helium, neon, and argon are in a column made up of gases. (The actual, formal determinant in the ordering is something called their electron valences, for which you will have to enroll in night classes if you wish an understanding.) The horizontal rows, meanwhile, arrange the chemicals in ascending order by the number of protons in their nuclei—what is known as their atomic number.

The structure of atoms and the significance of protons will come in a following chapter, so for the moment all that is necessary is to appreciate the organizing principle: hydrogen has just one proton, and so it has an atomic number of one and comes first on the chart; uranium has ninety-two protons, and so it comes near the end and has an atomic number of ninety-two. In this sense, as Philip Ball has pointed out, chemistry really is just a matter of counting. (Atomic number, incidentally, is not to be confused with atomic weight, which is the number of protons plus the number of neutrons in a given element.) There was still a great deal that wasn't known or understood. Hydrogen is the most common element in the universe, and yet no one would guess as much for another thirty years. Helium, the second most abundant element, had only been found the year before—its existence hadn't even been suspected before that—and then not on Earth but in the Sun, where it was found with a spectroscope during a solar eclipse, which is why it honors the Greek sun god Helios. It wouldn't be isolated until 1895. Even so, thanks to Mendeleev's invention, chemistry was now on a firm footing.

For most of us, the periodic table is a thing of beauty in the abstract, but for chemists it established an immediate orderliness and clarity that can hardly be overstated. “Without a doubt, the Periodic Table of the Chemical Elements is the most elegant organizational chart ever devised,” wrote Robert E. Krebs in *The History and Use of Our Earth’s Chemical Elements*, and you can find similar sentiments in virtually every history of chemistry in print.

Today we have “120 or so” known elements—ninety-two naturally occurring ones plus a couple of dozen that have been created in labs. The actual number is slightly contentious because the heavy, synthesized elements exist for only millionths of seconds and chemists sometimes argue over whether they have really been detected or not. In Mendeleev’s day just sixty-three elements were known, but part of his cleverness was to realize that the elements as then known didn’t make a complete picture, that many pieces were missing. His table predicted, with pleasing accuracy, where new elements would slot in when they were found.

No one knows, incidentally, how high the number of elements might go, though anything beyond 168 as an atomic weight is considered “purely speculative,” but what is certain is that anything that is found will fit neatly into Mendeleev’s great scheme.

The nineteenth century held one last great surprise for chemists. It began in 1896 when Henri Becquerel in Paris carelessly left a packet of uranium salts on a wrapped photographic plate in a drawer. When he took the plate out some time later, he was surprised to discover that the salts had burned an impression in it, just as if the plate had been exposed to light. The salts were emitting rays of some sort.

Considering the importance of what he had found, Becquerel did a very strange thing: he turned the matter over to a graduate student for investigation. Fortunately the student was a recent émigré from Poland named Marie Curie. Working with her new husband, Pierre, Curie found that certain kinds of rocks poured out constant and extraordinary amounts of energy, yet without diminishing in size or changing in any detectable way. What she and her husband couldn’t know—what no one could know until Einstein explained things the following decade—was that the rocks were converting mass into energy in an exceedingly efficient way. Marie Curie dubbed the effect “radioactivity.” In the process of their work, the Curies also found two new elements—polonium, which they named after her native country, and radium. In 1903 the Curies and Becquerel were jointly awarded the Nobel Prize in physics. (Marie Curie would win a second prize, in chemistry, in 1911, the only person to win in both chemistry and physics.)

At McGill University in Montreal the young New Zealand-born Ernest Rutherford became interested in the new radioactive materials. With a colleague named Frederick Soddy he discovered that immense reserves of energy were bound up in these small amounts of matter, and that the radioactive decay of these reserves could account for most of the Earth’s warmth. They also discovered that radioactive elements decayed into other elements—that one day you had an atom of uranium, say, and the next you had an atom of lead. This was truly extraordinary. It was alchemy, pure and simple; no one had ever imagined that such a thing could happen naturally and spontaneously.

Ever the pragmatist, Rutherford was the first to see that there could be a valuable practical application in this. He noticed that in any sample of radioactive material, it always took the



same amount of time for half the sample to decay—the celebrated half-life—and that this steady, reliable rate of decay could be used as a kind of clock. By calculating backwards from how much radiation a material had now and how swiftly it was decaying, you could work out its age. He tested a piece of pitchblende, the principal ore of uranium, and found it to be 700 million years old—very much older than the age most people were prepared to grant the Earth.

In the spring of 1904, Rutherford traveled to London to give a lecture at the Royal Institution—the august organization founded by Count von Rumford only 105 years before, though that powdery and periwigged age now seemed a distant eon compared with the roll-your-sleeves-up robustness of the late Victorians. Rutherford was there to talk about his new disintegration theory of radioactivity, as part of which he brought out his piece of pitchblende. Tactfully—for the aging Kelvin was present, if not always fully awake—Rutherford noted that Kelvin himself had suggested that the discovery of some other source of heat would throw his calculations out. Rutherford had found that other source. Thanks to radioactivity the Earth could be—and self-evidently was—much older than the twenty-four million years Kelvin’s calculations allowed.

Kelvin beamed at Rutherford’s respectful presentation, but was in fact unmoved. He never accepted the revised figures and to his dying day believed his work on the age of the Earth his most astute and important contribution to science—far greater than his work on thermodynamics.

As with most scientific revolutions, Rutherford’s new findings were not universally accepted. John Joly of Dublin strenuously insisted well into the 1930s that the Earth was no more than eighty-nine million years old, and was stopped only then by his own death. Others began to worry that Rutherford had now given them too much time. But even with radiometric dating, as decay measurements became known, it would be decades before we got within a billion years or so of Earth’s actual age. Science was on the right track, but still way out.

Kelvin died in 1907. That year also saw the death of Dmitri Mendeleev. Like Kelvin, his productive work was far behind him, but his declining years were notably less serene. As he aged, Mendeleev became increasingly eccentric—he refused to acknowledge the existence of radiation or the electron or anything else much that was new—and difficult. His final decades were spent mostly storming out of labs and lecture halls all across Europe. In 1955, element 101 was named mendelevium in his honor. “Appropriately,” notes Paul Strathern, “it is an unstable element.”

Radiation, of course, went on and on, literally and in ways nobody expected. In the early 1900s Pierre Curie began to experience clear signs of radiation sickness—notably dull aches in his bones and chronic feelings of malaise—which doubtless would have progressed unpleasantly. We shall never know for certain because in 1906 he was fatally run over by a carriage while crossing a Paris street.

Marie Curie spent the rest of her life working with distinction in the field, helping to found the celebrated Radium Institute of the University of Paris in 1914. Despite her two Nobel Prizes, she was never elected to the Academy of Sciences, in large part because after the death of Pierre she conducted an affair with a married physicist that was sufficiently indiscreet to scandalize even the French—or at least the old men who ran the academy, which is perhaps another matter.

For a long time it was assumed that anything so miraculously energetic as radioactivity must be beneficial. For years, manufacturers of toothpaste and laxatives put radioactive thorium in their products, and at least until the late 1920s the Glen Springs Hotel in the Finger Lakes region of New York (and doubtless others as well) featured with pride the therapeutic effects of its “Radioactive mineral springs.” Radioactivity wasn’t banned in consumer products until 1938. By this time it was much too late for Madame Curie, who died of leukemia in 1934. Radiation, in fact, is so pernicious and long lasting that even now her papers from the 1890s—even her cookbooks—are too dangerous to handle. Her lab books are kept in lead-lined boxes, and those who wish to see them must don protective clothing.

Thanks to the devoted and unwittingly high-risk work of the first atomic scientists, by the early years of the twentieth century it was becoming clear that Earth was unquestionably venerable, though another half century of science would have to be done before anyone could confidently say quite how venerable. Science, meanwhile, was about to get a new age of its own—the atomic one.