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 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.

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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

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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 6.0221367×10^{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.

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 tidyings-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 Mendeleyev.

Mendeleyev (also sometimes spelled Mendeleev or Mendeléef) 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 Mendeleyevs 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 Mendeleyevs. 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. Mendeleyev 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.

Mendeleyev 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).

Mendeleyev'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, droller 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.

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Mendeleyev 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.

Mendeleyev 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 Mendeleyev'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 Mendeleyev'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 Mendeleyev'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.

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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.)

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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