INTERCHAPTER B

A Brief History of the Periodic Table

Photo to come

A Chinese periodic table in calligraphic script. The Chinese language has its own unique ideographs to represent each element. Various portions of each ideograph show whether the element in its natural state is a gas, a liquid, a metal, or a non-metal.

No other discipline has anything quite like the periodic table of the elements. Every general chemistry textbook and practically all other chemistry textbooks display the periodic table in some prominent place, and there is one hanging in almost every chemistry lecture hall and laboratory around the world. Its development has a long history, which we shall briefly present in this Interchapter.

B-1. Early Tables of Elements Were Little More Than Lists

As more and more elements were discovered in the early 1800s, chemists started looking for some relations in their physical and chemical properties. Up to this time, the elements were placed in lists with no particular order. One early attempt to organize the elements was by the German chemist Johann Döbereiner in 1817. Döbereiner noticed that certain sets of three elements had similar chemical properties. For example, lithium, sodium, and potassium, which had recently been discovered by electrolysis, have similar chemical properties, as we discussed in Chapter 3. He called such groups *triads*. Some other triads known at that time were chlorine, bromine, and iodine; calcium, strontium, and barium; and sulfur, selenium, and tellurium. Table B.1 lists two of these triads.

Döbereiner's ideas weren't taken too seriously by other chemists because only a few elements fit into the triad scheme. As more and more elements were discovered, scientists found other groups with similar chemical properties. However, none yielded a useful unifying principle. One reason was that not enough elements had been discovered yet to discern a pattern for organizing them in a systematic manner. Furthermore, the state of atomic masses was a mess in the early 1800s. At the time, chemists thought that the formula for water was HO and that of ammonia was NH, which led to oxygen having an atomic mass of 8 instead of 16 and nitrogen having an atomic mass of 4.7 instead of 14 on our current scale.

TABLE B.1 Two of Döbereiner's triads and the atomic masses of the elements. Notice that the atomic mass of the middle element is the average of the one above and below it.

Element	Atomic mass	Element	Atomic mass
lithium	6.9	sulfur	32
sodium	23	selenium	79
potassium	39	tellurium	128

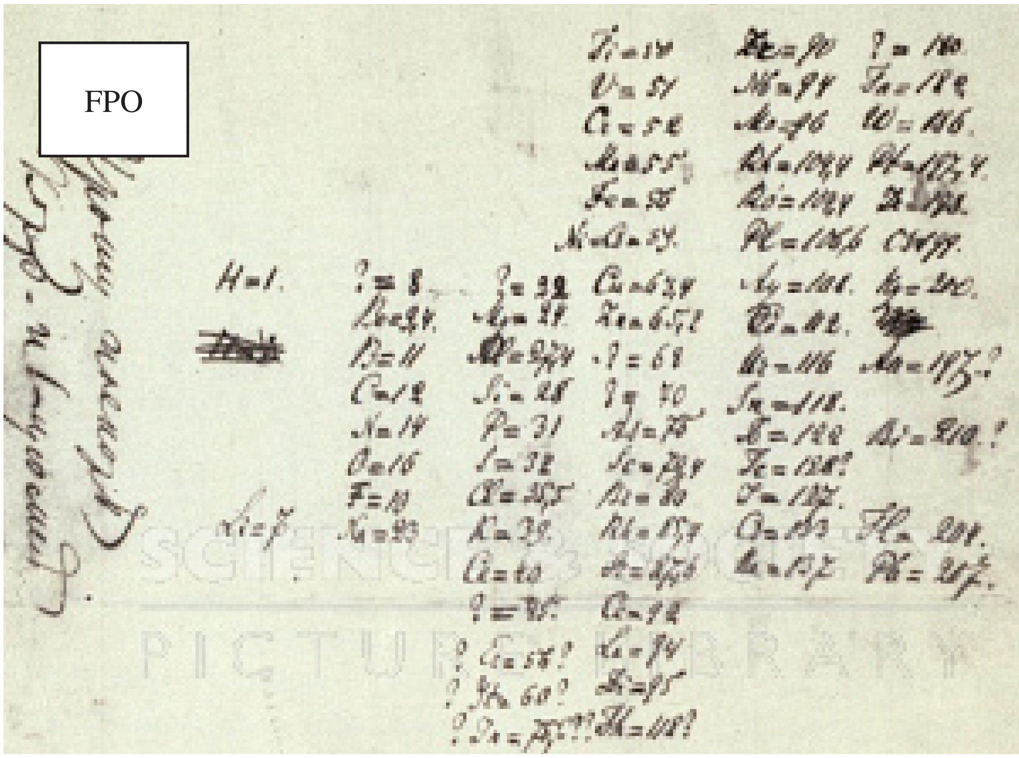
B-2. The Systematic Determination of Atomic Masses Provided a Basis for More Modern Tables

All this was to change in 1860. By this time, over 60 elements had been discovered, and at an international conference, the Italian chemist Stanislao Cannizzaro (Chapter 13 Frontispiece) presented a revised self-consistent system of atomic masses. Many new classification schemes using Cannizzaro's masses were proposed based on arranging the elements by their atomic masses and their chemical properties.

Between 1863 and 1865, the British chemist John Newlands showed that when the elements known at the time were arranged in order of increasing atomic mass, many of their chemical and physical properties repeated for each eighth element. Newlands referred to this pattern as the *law of octaves*. His table worked fine through calcium, but there was no chemical relationship between the metals in the remaining columns and those in the first two columns. His ideas were treated with less than enthusiasm; at a meeting of the Chemical Society in London, he was ridiculed by being asked if he had considered arranging the elements alphabetically because coincidences among the positions were likely to be found in almost any arrangement. Nevertheless, there was certainly a glimmer of insight in his attempt.

B-3. Mendeleev's Table Predicted Several New Elements

The 1860s saw several significant advances over Newlands's proposal, but it was a Siberian-born Russian chemist, Dmitri Mendeleev (Chapter 3 Frontispiece), who proposed a periodic table much like the one we use today (Figures B.1 and B.2). As a 26-year-old, Mendeleev attended the 1860 chemical conference in which Cannizzaro set forth what was finally a correct list of atomic masses (with a few small exceptions). In the following years, Mendeleev toyed with a number of arrangements, and in 1869 he published his final thoughts in an obscure Russian journal, but a German translation appeared shortly thereafter that gave his periodic arrangement a wide



Figures B.1. Mendeleev's first periodic table, published in 1869. The arrangement of the elements in the table is based on chemical properties and atomic mass. As you can see, Mendeleev arranged his table vertically by mass rather than horizontally as we do today.

scientific audience. He also incorporated his periodic table into his popular textbook, *Principles of Chemistry*, which ran through many editions in Russian, German, English, and French.

In designing his table, Mendeleev made a number of modifications based on his chemical knowledge. For instance, beryllium was thought to have a mass of 14 because of the mistaken formula $Be_2O_3(s)$, instead of $BeO(s)$. This placed it incorrectly into the same group as aluminum. Realizing that the chemistry of beryllium was similar to that of the alkaline-earth metals, he assumed that the formula of the oxide was actually $BeO(s)$ instead of $Be_2O_3(s)$, giving beryllium an atomic mass of 9.4 and correctly placing beryllium before magnesium in his table. In addition, he had the good judgment to interchange the positions of tellurium and iodine even though their atomic masses are 127.6 and 126.9, respectively.

More impressively, he left gaps in his table where it seemed that the periodicity did not occur. He had the brilliant insight that these gaps represented elements that had not yet been discovered. In particular, he selected three gaps, one that occurred after calcium and two that occurred below aluminum and silicon, and predicted the properties of the presumed undiscovered elements based upon the properties of

1							H							Li					
2								Be	B	C	N	O	F	Na					
3								Mg	Al	Si	P	S	Cl	K	Ca	–	Er?	Y?	In?
4	Ti	V	Cr	Mn	Fe	Ni,Co	Cu	Zn	–	–	As	Se	Br	Rb	Sr	Ce	La	Di	Tb
5	Zr	Nb	Mo	Rh	Ru	Pd	Ag	Cd	U	Sn	Sb	Te	I	Cs	Ba				
6	–	Ta	W	Pt	Ir	Os	Hg	–	Au	–	Bi	–	–	Tl	Pb				

Figures B.2. Mendeleev's table rotated to show the periods as rows rather than columns.

A MOTHER'S LOVE

Mendeleev's mother, Maria Dmitrievna Korníleva (d. 1851), was born into a merchant family in Siberia in the 1700s. Her husband, Ivan Pavlovich Mendeleev (d. 1848), was the headmaster of a local secondary school. Dmitri was the last of her 14 children. When Dmitri was 13, Ivan went blind from cataracts and was forced to retire on an inadequate pension. Having to support the family, Maria became the manager of her family's glass factory. In 1848 the factory burned down and shortly afterwards Ivan died of consumption.

Nearly destitute at 57, she and her two youngest children, Dmitri and Elisabeth, set out from Siberia on foot, walking and hitchhiking the 2150 km (1300 miles) to Moscow, where she hoped to see Dmitri enter college. Due to political unrest and being from Siberia, Dmitri was barred from the university, and the family had to trek an additional 690 km (430 miles) to St. Petersburg. There a friend of Ivan's helped Dmitri enter a science teacher training program with a government scholarship in 1850. Her dream of seeing her son enter the university satisfied, Maria died of tuberculosis and exhaustion. Elisabeth passed away a few months later. Dmitri eulogized his mother in his chemistry text with the following dedication: *"She instructed by example, corrected with love, and in devoting her son to science, left Siberia with him, spending her last resources and strength. When dying she said, 'Refrain from illusions, insist on work and not on words. Patiently search divine and scientific truth.' . . . Dmitri Mendeleev regards as sacred a mother's dying words."*

the elements just above and below the gaps. Using the Sanskrit prefix *eka*, meaning one, he named the "undiscovered" elements eka-boron, eka-aluminum, and eka-silicon. Table B.2 compares his predicted properties of eka-silicon with those of what we now call germanium, which was discovered about 20 years later.

Mendeleev's predictions proved astonishingly accurate. In 1875 the French chemist Paul-Emile Lecoq de Boisbaudran discovered a metal that he named gallium. Mendeleev suggested that this was probably his predicted eka-aluminum. Lecoq, afraid that Mendeleev was claiming priority for his discovery, adamantly argued that his element had different physical properties from those Mendeleev had predicted. However, later measurements showed Lecoq's measurements of these properties in error and Mendeleev's predictions for these correct to within a percent, much to Lecoq's chagrin. This much publicized debate over gallium helped bring Mendeleev's table to the attention of the general public.

Not all of Mendeleev's predictions proved true. At the time only six of the fourteen rare-earth metals had been discovered and so Mendeleev erroneously squeezed these into the body of his table, resulting in erroneous gaps that were never filled.

Mendeleev was not the only person to develop a fairly complete periodic table during this period. About the same time that Mendeleev published his table, a German chemist, Lothar Meyer (Figure B.3), published one that was very similar to Mendeleev's, including the gaps that occurred after calcium and below aluminum and silicon. Meyer paid more attention to the periodicity of the physical properties of the elements, whereas Mendeleev focused on the periodicity of their chemical properties. Mendeleev was a little more adventurous in predicting the chemical properties of the presumably undiscovered elements

TABLE B.2 Mendeleev's predictions of the properties of what he called eka-silicon with what is now called germanium

	Eka-silicon (Ek) (Predicted)	Germanium (Observed)
atomic mass:	72	72.6
density:	$5.5\ g\cdot cm^{-3}$	$5.47\ g\cdot cm^{-3}$
formula of oxide:	EkO_2	GeO_2
formula of chloride salt:	$EkCl_4$	$GeCl_4$
density of the oxide:	$4.7\ g\cdot cm^{-3}$	$4.703\ g\cdot cm^{-3}$

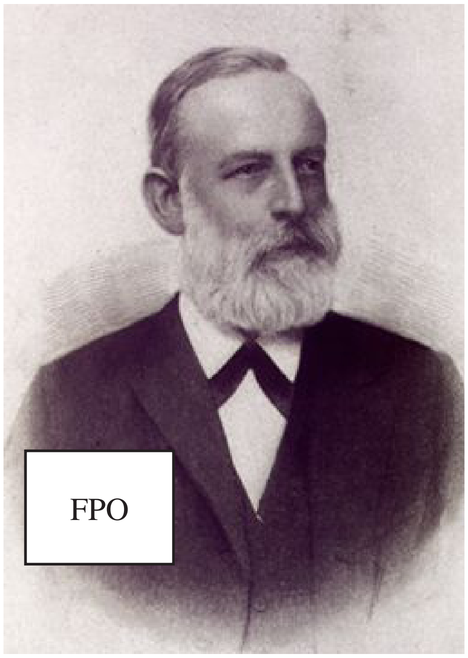


Figure B.3 Julius Lothar Meyer (1830–1895) was born in Varel, Germany. Meyer studied medicine in Zürich, earning a degree as a physician in 1854 and a Ph.D. at the University of Breslau in 1858. In 1876 Meyer became the first professor of chemistry at the University of Tübingen, a post he held until his death.

and also made allowances for a few discrepancies in atomic masses. Nevertheless, their tables were very similar and it is likely that both benefited from each other's work. Although both men are entitled to the honor of the discovery of the periodic table and each acknowledged this, Mendeleev has emerged as the primary author. It is interesting that Mendeleev lived until 1907, and so was eligible for a Nobel Prize, which was instituted in 1901, but never received one in spite of creating what is perhaps the best-known icon in all of science. Finally, in 1997 Mendeleev was awarded an even rarer distinction. Element 101, mendelevium (Md), was named in his honor.

B-4. New Discoveries Led to the Arrangement of Elements in the Modern Periodic Table

Following Mendeleev, the periodic table was to undergo further revisions. The first was the discovery of the noble gases by Lord Rayleigh and William Ramsay in 1893, which added a whole new family of elements to the table (Interchapter K). The noble gases are assigned the far right-hand column in the modern periodic table. It was a great achievement that this entire new group of elements was so readily incorporated into the periodic table.

Although the periodic properties of the elements are displayed when the elements are arranged in order of increasing atomic mass, there are occasional exceptions, such as with cobalt and nickel and with tellurium and iodine, where the order must be reversed. The order did not seem to be strictly in terms of increasing atomic mass, but it was not clear just what it was. It became common practice to assign numbers to the elements based on their position in the table, with hydrogen assigned the number 1. No significance was attributed to these numbers at the time. Nevertheless, the system was fairly widely used, and they were called atomic numbers.

In 1913, the English physicist Henry Moseley (Figure B.4) analyzed the X-ray spectra of all the elements known at the time and found that the square roots of certain X-ray frequencies were directly proportional to the position of the elements in the periodic table or to their atomic number. It turned out that the atomic numbers were more fundamental than the atomic masses. Shortly thereafter, it was demonstrated that the atomic number of an element is equal to the number of protons in the nucleus. This discovery finally elucidated the fundamental order underlying Mendeleev's table—when ordered according to atomic number, the whole table fell into place.

A further understanding of chemical order and periodicity came with the advent of modern quantum theory, showing that the chemical properties of elements in the same families are derived from similar outer-electron configurations. We shall study this in detail in Chapters 4 and 5.

The final arrangement of the periodic table came in the 1940s when the American chemist Glenn Seaborg (Figure B.5) demonstrated that the newly discovered transuranium (actinide) metals were chemically similar to the rare-earth (lanthanide) metals, and should be placed below them in the table. Prior to that, this entire set of elements was placed in the bulk of the periodic table, which led to a number of inconsistencies.

Over the years many variants on the periodic table have been suggested, from spirals to three-dimensional arrangements, some of which are quite bizarre. So far none has supplanted the form familiar to most of us.

Figure B.4 Henry Moseley (1887–1915) was born in Weymouth on the southwest coast of England. After receiving his Ph.D. in physics from Oxford University, he initiated a research program on the X-ray spectra of the elements at Manchester University. This research led to the concept of atomic number and to the elucidation of the position of the elements in the periodic table. In 1914, he returned to Oxford to continue his research, but as soon as World War I started, he enlisted as an artillery officer in the British army. Tragically, he was killed in the Battle of Gallipoli in August of 1915 at the age of 27. Moseley was on track to a brilliant scientific career, and many of his colleagues were convinced that he would have received the Nobel Prize had he lived. (Nobel Prizes are not awarded posthumously.) Because of Moseley's untimely death, the British government, as well as many others, instituted a policy that scientists not be allowed to enlist for combat duties.

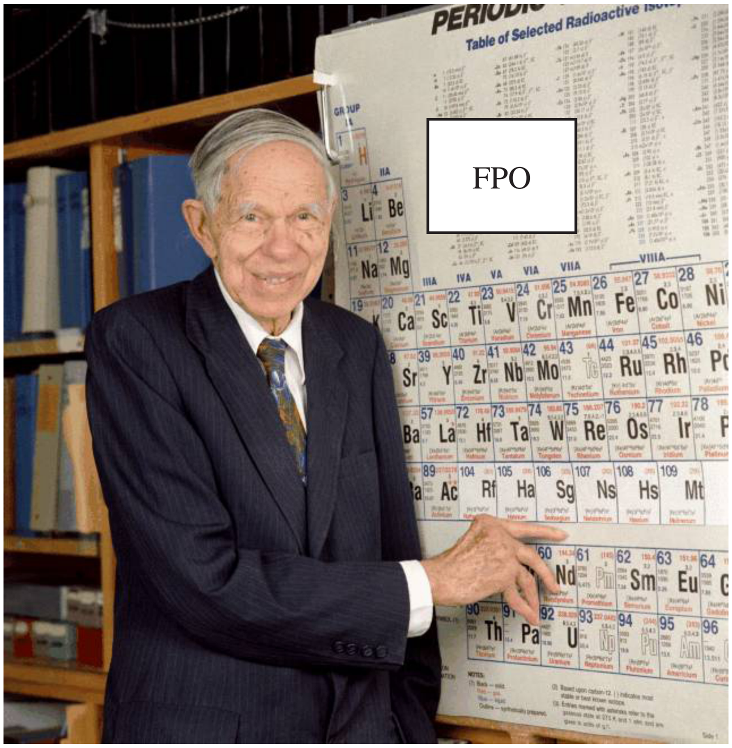


Figure B.5 Glenn Seaborg (1912–1999) worked his way through UCLA as an undergraduate and earned his Ph.D. from the University of California at Berkeley. In 1940 he codiscovered plutonium and later worked on the Manhattan Project during World War II. After returning to Berkeley, he published a revised periodic table locating the transuranium elements below the rare-earth elements, or what is now our modern form. In 1951 he shared the Nobel Prize in Chemistry with Edwin Macmillan for their codiscovery of the transuranium elements. Seaborg served as chair of the Atomic Energy Commission in Washington under three administrations, where he promoted treaties to halt nuclear testing and proliferation. In 1994, element 106 was officially named *Seaborgium* in his honor.