

## The Periodic Table Of Elements

1 H Hydrogen 1.008																	2 He Helium 4.0026	
3 Li Lithium 6.938	4 Be Beryllium 9.012											5 B Boron 10.806	6 C Carbon 12.0006	7 N Nitrogen 14.0064	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.1797	
11 Na Sodium 22.989	12 Mg Magnesium 24.304											13 Al Aluminium 26.9815	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.059	17 Cl Chlorine 35.446	18 Ar Argon 39.948	
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.9559	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.630	33 As Arsenic 74.922	34 Se Selenium 78.971	35 Br Bromine 79.901	36 Kr Krypton 83.798	
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.9058	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.95	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.414	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.904	54 Xe Xenon 131.293	
55 Cs Caesium 132.905	56 Ba Barium 137.327	57-71 Lanthanoids*		72 Hf Hafnium 178.49	73 Ta Tantalum 180.948	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.967	80 Hg Mercury 200.592	81 Tl Thallium 204.382	82 Pb Lead 207.2	83 Bi Bismuth 208.980	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
87 Fr Francium (223)	88 Ra Radium (226)	89-103 Actinoids**		104 Rf Rutherfordium (267)	105 Db Dubnium (268)	106 Sg Seaborgium (269)	107 Bh Bohrium (270)	108 Hs Hassium (271)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (282)	112 Cn Copernicium (285)	113 Nh Nihonium (286)	114 Fl Flerovium (289)	115 Mc Moscovium (290)	116 Lv Livermorium (293)	117 Ts Tennessine (294)	118 Og Oganesson (294)
Lanthanoids		57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.259	69 Tm Thulium 168.934	70 Yb Ytterbium 173.045	71 Lu Lutetium 174.968		
Actinoids		89 Ac Actinium (227)	90 Th Thorium 232.0377	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (260)		

The periodic table of elements represents a collaborative discovery that crosses centuries, continents, and scientific disciplines. Many researchers contributed to solving the atomic puzzle, and in so doing, created a valuable tool for both practical and pedagogical chemistry.

Written by Victoria Bruce

By the late 1860s, University of Saint Petersburg chemistry professor Dmitri Mendeleev was working on a second volume of his 1861 textbook, “Principles of Chemistry.” Looking to find a simple way to classify elements “by some exact, definite principle,” he drew up a table. A pattern emerged: a very obvious periodicity of chemical behaviors as a function of atomic mass. “I am quite conscious that this attempt is not final,” Mendeleev wrote. Nonetheless, he believed that the periodicity would be proven to apply to “all elements whose atomic weights have been determined with some reliability.”

In March of 1869, Mendeleev delivered his discovery in a roughly drawn sketch to the Russian Chemical Society and published it later that year. Two contemporary chemists, Karlsruhe professor Lothar Meyer (Germany) and industrial chemist John Newlands (England), envisioned and published similar charts around the same time.

The table’s form has evolved over the decades. Starting with Mendeleev’s first published work on the periodic table in 1869, there were question marks noting gaps in knowledge, and copious disagreements on what should be placed where and why. Mendeleev’s work was groundbreaking to be sure, but it was an unfinished symphony that enticed chemists around the world to use the

latest discoveries and refined calculations to fill in the missing notes and tweak some of its suspect aspects.

In the U.S., several prominent chemists made vital contributions that substantially enhanced and fortified the periodic table over the next century. At Harvard University, Theodore W. Richards and his graduate students remeasured the atomic weight of over 30 elements to pinpoint accuracy, work that ultimately earned Richards a Nobel Prize in Chemistry. Later, during his investigation of lead, he found that its atomic mass depended on the metal’s source. The discovery validated British chemist Frederick Soddy’s theory of isotopes and provided nuance and depth to the ever-more-robust periodic table.

Richards and others provided sophisticated atomic mass measurements to U.S. Geological Survey Chief Chemist Frank W. Clarke, who in 1872 had been tasked to compile and produce an annual table of elemental weights. Clarke also chaired the International Committee on Atomic Weights, which published the table for an international audience, revising it annually until the work stalled in 1918 because of the ongoing First World War.

While Clarke and others were compiling data, Francis Preston Venable, a chemistry professor

at the University of North Carolina, wondered why the periodic table was not used more, especially by teachers. He came to the conclusion that Mendeleev's table and those created by others were not terribly inspiring. A clearer table, he believed, could be the basis for teaching an entire chemistry course.

In 1896, Venable published the first history of the periodic law. With his students in mind, Venable redrew the periodic table without the transition "periods" to simplify the graphic representation. He argued that his changes to Mendeleev's table were minor, but that they "certainly make the table an easier, more intelligible, and more useful one to the student." Confident in his ability to get complex topics across to students, in 1898 Venable co-wrote a chemistry textbook with James Lewis Howe, "Inorganic Chemistry According to the Periodic Law."

A quarter century after Venable's well-received textbook, one of the most popular chemistry texts ever written was published by Horace G. Deming, a University of Nebraska chemistry professor. Deming's 1923 "General Chemistry" was an instant hit.

In Deming's chapter on the periodic law he provided "Mendelejeff's [another of the multiple romanized spellings of his name] form, slightly modified." However, he directed students to his own "long form" periodic table, which was strategically printed inside the back cover of the book. Deming's new table separated elements in periods 2 and 3 by moving the first two all the way to the left and the following elements to the right. He also delineated the columns into A and B groups. For the first time, a periodic table design made clear how elements transition from main group elements to transition elements.

Deming's graphical representation of the elements also got positive reviews. In 1927, Royce H. LeRoy wrote that Deming's table represented a "very marked improvement over the original Mendeleef type as far as presentation to beginning classes is concerned."

The textbook continued into its sixth edition in 1952, more than a quarter-century after its launch. Chemical companies took Deming's user-friendly table, branded it with their company logos and printed charts the size of student notebooks. "General Chemistry" helped standardize and promote the use of

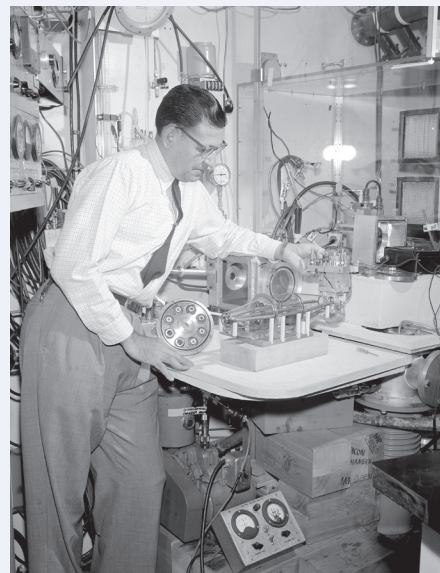
an enduring periodic table in a format that is still familiar today.

While Deming's version remained the most popular form of the periodic table into the mid-20<sup>th</sup> century, other discoveries were yet to come. Enter nuclear chemist and Manhattan Project scientist Glenn Seaborg. In 1944, Seaborg, Albert Ghiorso, and their colleagues at the Radiation Laboratory at the University of California, Berkeley (predecessor to the Lawrence Berkeley National Laboratory), were attempting to synthesize new elements beyond their newly created element plutonium.

Many scientists believed that the transuranic elements would fit within the periodic table's main body. Seaborg disagreed, arguing that the newest elements would behave like actinium and therefore needed to be grouped with it in their own pullout row beneath the lanthanide series.

In 1945 Seaborg published his hypothesis along with a table showing an "actinide series" that fell beneath the lanthanide row with empty squares following plutonium for yet-to-be-determined elements. "My theory required a major realignment of the periodic table of the elements," wrote Seaborg. "Senior colleagues counseled that advocating such a radical concept would ruin my scientific reputation. Fortunately for me, at the time my scientific reputation was nothing to worry about losing. And even more fortunate, I was right."

In 1951, Seaborg received the Nobel Prize in Chemistry, which he shared with Edwin M. McMillan "for their discoveries in the chemistry of the transuranium elements." The work of Seaborg and others in the Berkeley lab was extraordinary, and contributed to the synthesis of nine more transuranium elements in the actinide series, making a substantial addition to the periodic table. The final transactinide synthesized by Seaborg's team was element number 106 in 1974, which was later named after its creator. Colleagues said that Seaborg considered the addition of "seaborgium" to the periodic table an honor



**Albert Ghiorso with the target and detection apparatus used to discover element 104 (undated photo). Credit: Lawrence Berkeley National Laboratory**

even greater than winning the Nobel Prize.

In 2009, it was a partnership between American researchers from Vanderbilt University, Oak Ridge National Laboratory, the University of Tennessee-Knoxville and Lawrence Livermore National Laboratory, along with the Joint Institute for Nuclear Research in Russia, that filled in the second-to-final square in the periodic table's seventh row. Element 117 — the most recent element to be discovered — was later named tennessine to honor the state from which many of the researchers came. But this addition might not be the last periodic table revision. Researchers are now trying to discover elements even heavier than the heaviest known element: oganesson, element 118.

The tennessine team clearly stood on the shoulders of giants with their contribution, as did other researchers around the world and across the decades since Mendeleev's original table. It is with great reverence for one of the most important scientific collaborations of the last 150 years that we celebrate their collective achievements during the International Year of the Periodic Table.



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of the Periodic Table  
of Chemical Elements



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