The Periodic Table of the Elements

The president of the Inorganic Chemistry Division, Gerd Rosenblatt, recognizing that the periodic table of the elements found in the "Red Book" (Nomenclature of Inorganic Chemistry, *published in 1985) needed some updating—particularly elements above 103, including element 110 (darmstadtium)—made a formal request to Norman Holden and Tyler Coplen to prepare an updated table. This table can be found below, on the IUPAC Web site, and as a tear-off on the inside back cover of this issue.*

by Norman Holden and Ty Coplen

The Russian chemist Dmitri Ivanovich Mendeleev constructed his original periodic table in 1869 using as its organizing principle his formulation of the periodic law: if the chemical elements are arranged in the ascending order of their atomic weights, then at certain regular intervals (periods) elements occur having similar chemical and physical properties.

Mendeleev sensed that chemical behavior was more fundamental than atomic weight and left empty spaces in his table when chemical properties did not fit. He predicted that these missing elements would be discovered with appropriate atomic weight values and having the required properties. When gallium, scandium, and germanium were discovered over the next 15 years with the properties that Mendeleev predicted, the scientific world began to take his periodic table seriously.

In 1913, the English physicist Henry Gwyn Jeffreys Moseley compared the energy of the X-ray spectral lines of various elements against their atomic weight. He obtained an approximate straight-line graph. To avoid breaks in this graph, he found it necessary to place elements in the order demanded by the chemical properties rather than increasing atomic weight. Moseley's curve of X-ray lines indicated that every element has a constant value, its ordinal or atomic number, that increases by a constant amount from element to element. In 1920, Chadwick showed that the atomic number was the same as the number of protons in each element.

A problem for Mendeleev's table was the positioning of the rare earth or lanthanoid* elements. These elements had properties and atomic weight values similar to one another but that did not follow the regularities of the table. Eventually, they were placed in a separate area below the main table.

The Danish physicist Niels Henrik David Bohr proposed his electronic orbital structure of the atom in 1921, which explained the problem of the rare earth elements. The electrons in the outermost and the penultimate orbits are called valence electrons since generally their actions account for the valence of the element (i.e., electrons capable of taking part in the links between atoms). Chemical behavior of an element depends on its valence electrons, so that when only inner orbit electrons are changing from one element to another, there is not much difference in the chemical properties between the elements.

The elements from actinium through uranium (along with neptunium through curium when they were first synthesized) were originally placed with the main table elements, in spite of problems with their chemical properties. In 1946, the American chemist Glenn

Key:

atomic number
Symbol
name
standard atomic weight

1	2	3	4	5	6	7	8	9	10	11	12
1 **H** hydrogen 1.007 94(7)											
3 **Li** lithium 6.941(2)	4 **Be** beryllium 9.012 182(3)										
11 **Na** sodium 22.989 770(2)	12 **Mg** magnesium 24.3050(6)										
19 **K** potassium 39.0983(1)	20 **Ca** calcium 40.078(4)	21 **Sc** scandium 44.955 910(8)	22 **Ti** titanium 47.867(1)	23 **V** vanadium 50.9415(1)	24 **Cr** chromium 51.9961(6)	25 **Mn** manganese 54.938 049(9)	26 **Fe** iron 55.845(2)	27 **Co** cobalt 58.933 200(9)	28 **Ni** nickel 58.6934(2)	29 **Cu** copper 63.546(3)	30 **Zn** zinc 65.409(4)
37 **Rb** rubidium 85.4678(3)	38 **Sr** strontium 87.62(1)	39 **Y** yttrium 88.905 85(2)	40 **Zr** zirconium 91.224(2)	41 **Nb** niobium 92.906 38(2)	42 **Mo** molybdenum 95.94(2)	43 **Tc** technetium [97.9072]	44 **Ru** ruthenium 101.07(2)	45 **Rh** rhodium 102.905 50(2)	46 **Pd** palladium 106.42(1)	47 **Ag** silver 107.8682(2)	48 **Cd** cadmium 112.411(8)
55 **Cs** caesium 132.905 45(2)	56 **Ba** barium 137.327(7)	57-71 lanthanoids	72 **Hf** hafnium 178.49(2)	73 **Ta** tantalum 180.9479(1)	74 **W** tungsten 183.84(1)	75 **Re** rhenium 186.207(1)	76 **Os** osmium 190.23(3)	77 **Ir** iridium 192.217(3)	78 **Pt** platinum 195.078(2)	79 **Au** gold 196.966 55(2)	80 **Hg** mercury 200.59(2)
87 **Fr** francium [223.0197]	88 **Ra** radium [226.0254]	89-103 actinoids	104 **Rf** rutherfordium [261.1088]	105 **Db** dubnium [262.1141]	106 **Sg** seaborgium [266.1219]	107 **Bh** bohrium [264.12]	108 **Hs** hassium [277]	109 **Mt** meitnerium [268.1388]	110 **Ds** darmstadtium [271]	111 **Uuu** unununium [272]	
		57 **La** lanthanum 138.9055(2)	58 **Ce** cerium 140.116(1)	59 **Pr** praseodymium 140.907 65(2)	60 **Nd** neodymium 144.24(3)	61 **Pm** promethium [144.9127]	62 **Sm** samarium 150.36(3)	63 **Eu** europium 151.964(1)	64 **Gd** gadolinium 157.25(3)	65 **Tb** terbium 158.925 34(2)	66 **Dy** dysprosium 162.500(1)
		89 **Ac** actinium [227.0277]	90 **Th** thorium 232.0381(1)	91 **Pa** protactinium 231.035 88(2)	92 **U** uranium 238.028 91(3)	93 **Np** neptunium [237.0482]	94 **Pu** plutonium [244.0642]	95 **Am** americium [243.0614]	96 **Cm** curium [247.0704]	97 **Bk** berkelium [247.0703]	98 **Cf** californium [251.0796]

For a printable version of this table, see <www.iupac.org/reports/periodic_table/>. A tear-off copy is attached to the backcover of this issue of CI.

Theodore Seaborg suggested that these elements formed an actinoid group similar to the lanthanoid. Lawrencium completed the actinoid series and element 104 was placed in the seventh row of the main table.

There were conflicting claims of who first synthesized element 104 and the next few elements of the table for almost a quarter century. During this long impasse, Joseph Chatt (of IUPAC's Inorganic Chemistry Division) suggested the use of a Greco-Roman naming scheme to provide a provisional IUPAC name with a three letter symbol (e.g., element 111 would have the name unununium with a symbol Uuu). Eventually, a joint working party from IUPAC and from the International Union of Pure and Applied Physics (IUPAP) was formed to review the scientific data for elements 104 through 109 and to resolve the impasse. The joint IUPAC/IUPAP working party decided to continue resolving the problem of determining the first synthesizer for future elements. The group determined that element 110 was initially made by the German group at the Heavy Ion facility in Darmstadt, Germany. The Germans suggested the name darmstadtium with the symbol Ds, which are now accepted both by IUPAC and IUPAP.

In keeping with the traditional use of atomic weight values in the periodic table, the latest (2001) IUPAC approved Standard Atomic Weight values are listed on the table with the uncertainty in the last figure shown in parentheses. These values are taken from table 1 of the "Atomic Weights of the Elements 2001" (IUPAC technical report, *Pure Appl. Chem.* **75**, 1107–1122 [2003]). For elements without stable nuclides or long-lived nuclides with normal terrestrial abundances of those nuclides, the atomic weights reported provides table 3 with either the atomic mass or, when that parameter is unknown, merely the atomic mass number (number of protons and neutrons in the nucleus) of the most stable nuclide of that element (i.e., the nuclide having the longest half-life). This value from table 3 of the report is shown on the periodic table in square brackets for many of the elements, including all elements above uranium. Thus, element 100 is listed as "[257.0951]." Otherwise, the mass number of the longest lived nuclide is listed, such as [277] for hassium. One element deserves a special comment in this regard. Element 110, darmstadtium (Ds), is listed in table 3 of the report [281]. Because the half-life of 1.6 min for ^{281}Ds was determined from only a single decay, it was decided instead to give in the periodic table the mass number of a nuclide that has the longest half-life and that confirms the discovery of Ds. This is ^{271}Ds; thus, [271] is listed for element 110.

13	14	15	16	17	18
					2 **He** helium 4.002 602(2)
5 **B** boron 10.811(7)	6 **C** carbon 12.0107(8)	7 **N** nitrogen 14.0067(2)	8 **O** oxygen 15.9994(3)	9 **F** fluorine 18.998 4032(5)	10 **Ne** neon 20.1797(6)
13 **Al** aluminium 26.981 538(2)	14 **Si** silicon 28.0855(3)	15 **P** phosphorus 30.973 761(2)	16 **S** sulfur 32.065(5)	17 **Cl** chlorine 35.453(2)	18 **Ar** argon 39.948(1)
31 **Ga** gallium 69.723(1)	32 **Ge** germanium 72.64(1)	33 **As** arsenic 74.921 60(2)	34 **Se** selenium 78.96(3)	35 **Br** bromine 79.904(1)	36 **Kr** krypton 83.798(2)
49 **In** indium 114.818(3)	50 **Sn** tin 118.710(7)	51 **Sb** antimony 121.760(1)	52 **Te** tellurium 127.60(3)	53 **I** iodine 126.904 47(3)	54 **Xe** xenon 131.293(6)
81 **Tl** thallium 204.3833(2)	82 **Pb** lead 207.2(1)	83 **Bi** bismuth 208.980 38(2)	84 **Po** polonium [208.9824]	85 **At** astatine [209.9871]	86 **Rn** radon [222.0176]

67 **Ho** holmium 164.930 32(2)	68 **Er** erbium 167.259(3)	69 **Tm** thulium 168.934 21(2)	70 **Yb** ytterbium 173.04(3)	71 **Lu** lutetium 174.967(1)
99 **Es** einsteinium [252.0830]	100 **Fm** fermium [257.0951]	101 **Md** mendelevium [258.0984]	102 **No** nobelium [259.1010]	103 **Lr** lawrencium [262.1097]

Element 111 has also been acknowledged by the joint IUPAC/IUPAP working party to have first been synthesized by the same German group at Darmstadt, but a name has not yet been suggested. It is shown on the table with its IUPAC provisional name and symbol "Uuu." The elements with atomic numbers 112, 114, and 116 have been reported in the scientific literature, but have not yet been authenticated by the IUPAC/IUPAP working party, so they do not yet merit a place in the table.

Finally, for American readers, it is noted that alternate English language spellings for the names of aluminum and cesium are used in the USA and do not constitute erroneous spellings.

---

*The 1985 "Red Book" (p. 45) indicates that the following collective names for groups of atoms are IUPAC-approved: actinoids or actinides, lanthanoids or lanthanides. The note that accompanied that statement explained that although actinoid means "like actinium" and so should not include actinium, actinium has become common usage. Similarly, lanthanoid. The ending "-ide" normally indicates a negatives ion, and therefore "lanthanoid" and "actinoid" are preferred to "lanthanide" and "actinide." However, owing to wide current use, "lanthanide" and "actinide" are still allowed.

Norman Holden <holden@bnl.gov> and Ty Coplen <tbcoplen@usgs.gov> are members of the IUPAC Inorganic Chemistry Division. NH is at the National Nuclear Data Center of the Brookhaven National Laboratory, in Upton, New York, and TC is with the U.S. Geological Survey, in Reston, Virginia, USA.

www.iupac.org/general/FAQs/elements.html