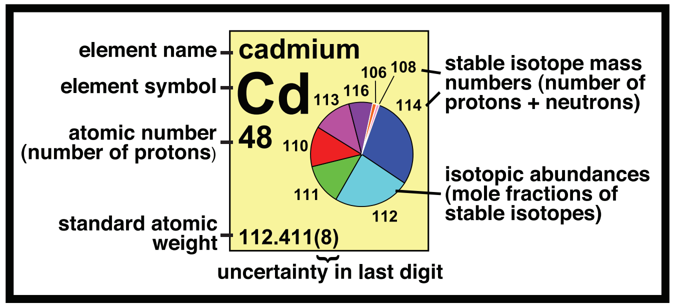
CCE2011-00 3a

IUPAC Periodic Table of the Isotopes

- Element has two or more stable isotopes. Atomic weight and isotopic abundances of element vary in naturally occurring materials. The lower and upper bounds of atomic weight have been assessed by IUPAC and are presented as the standard atomic weight within square brackets, [ ].
- Element has two or more stable isotopes and the standard atomic weight is not a constant of nature. The lower and upper bounds of the standard atomic weight have not been evaluated by IUPAC yet.
- Element has one stable isotope and its standard atomic weight is a constant of nature.
- Element has no stable isotopes. Thus, no standard atomic weight exists.



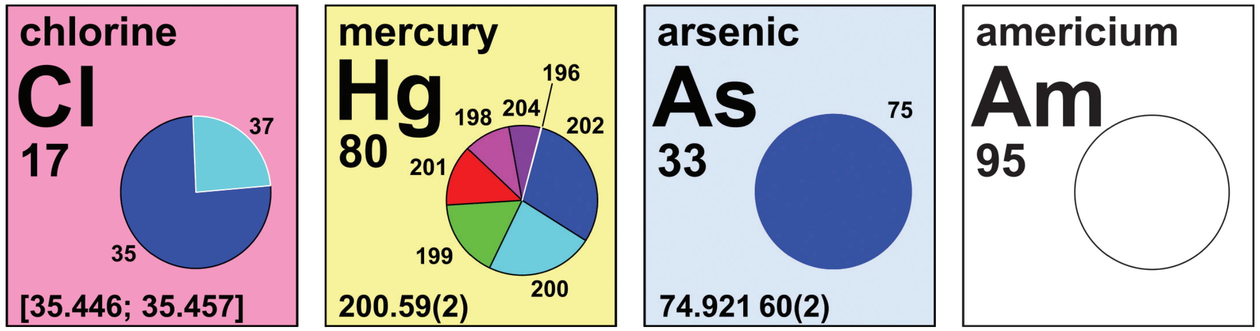
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
hydrogen H 1 1, 2 [1.007 84; 1.008 11]																	helium He 2 3, 4 4.002 602(2)
lithium Li 3 6, 7 [6.938; 6.997]	beryllium Be 4 9 9.012 182(3)											boron B 5 10, 11 [10.806; 10.821]	carbon C 6 12, 13 [12.0096; 12.0116]	nitrogen N 7 14, 15 [14.006 43; 14.007 28]	oxygen O 8 16, 17, 18 [15.999 03; 15.999 77]	fluorine F 9 19 18.998 4032(5)	neon Ne 10 20, 21, 22 20.1797(6)
sodium Na 11 23 22.989 769 28(2)	magnesium Mg 12 24, 25, 26 24.3050(6)											aluminium (aluminum) Al 13 27 26.981 5386(8)	silicon Si 14 28, 29, 30 [28.084; 28.086]	phosphorus P 15 31 30.973 762(2)	sulfur S 16 32, 33, 34, 36 [32.059; 32.076]	chlorine Cl 17 35, 37 [35.446; 35.457]	argon Ar 18 36, 38, 40 39.948(1)
potassium K 19 39, 40, 41 39.0983(1)	calcium Ca 20 40, 42, 43, 44, 46, 48 40.078(4)	scandium Sc 21 45 44.955 912(6)	titanium Ti 22 46, 47, 48, 49, 50 47.867(1)	vanadium V 23 50, 51 50.9415(1)	chromium Cr 24 50, 52, 53, 54 51.9961(6)	manganese Mn 25 55 54.938 045(5)	iron Fe 26 54, 56, 57, 58 55.845(2)	cobalt Co 27 59 58.933 195(5)	nickel Ni 28 58, 60, 61, 62, 64 58.6934(4)	copper Cu 29 63, 65 63.546(3)	zinc Zn 30 64, 66, 67, 68, 70 65.38(2)	gallium Ga 31 69, 71 69.723(1)	germanium Ge 32 70, 72, 73, 74, 76 72.63(1)	arsenic As 33 75 74.921 60(2)	selenium Se 34 74, 76, 77, 78, 80, 82 78.96(3)	bromine Br 35 79, 81 79.904(1)	krypton Kr 36 78, 80, 82, 83, 84, 86 83.798(2)
rubidium Rb 37 85, 87 85.4678(3)	strontium Sr 38 84, 86, 87, 88 87.62(1)	yttrium Y 39 89 88.905 85(2)	zirconium Zr 40 90, 91, 92, 94, 96 91.224(2)	niobium Nb 41 93 92.906 38(2)	molybdenum Mo 42 92, 94, 95, 96, 97, 98, 100 95.96(2)	technetium Tc 43	ruthenium Ru 44 96, 98, 99, 100, 101, 102, 104 101.07(2)	rhodium Rh 45 103 102.905 50(2)	palladium Pd 46 102, 104, 105, 106, 108, 110 106.42(1)	silver Ag 47 107, 109 107.8682(2)	cadmium Cd 48 106, 108, 110, 111, 112, 113, 114, 116 112.411(8)	indium In 49 113, 115 114.818(3)	tin Sn 50 112, 114, 115, 116, 117, 118, 119, 120, 122, 124 118.710(7)	antimony Sb 51 121, 123 121.760(1)	tellurium Te 52 120, 122, 123, 124, 125, 126, 128, 130 127.60(3)	iodine I 53 127 126.904 47(3)	xenon Xe 54 124, 126, 128, 129, 130, 131, 132, 134, 136 131.293(6)
caesium (cesium) Cs 55 133 132.905 4519(2)	barium Ba 56 130, 132, 134, 135, 136, 137, 138 137.327(7)	57 - 71 lanthanoids	hafnium Hf 72 174, 176, 177, 178, 179, 180 178.49(2)	tantalum Ta 73 180, 181 180.947 88(2)	tungsten W 74 180, 182, 183, 184, 186 183.84(1)	rhenium Re 75 185, 187 186.207(1)	osmium Os 76 184, 186, 187, 188, 189, 190, 192 190.23(3)	iridium Ir 77 191, 193 192.217(3)	platinum Pt 78 190, 192, 194, 195, 196, 198 195.084(9)	gold Au 79 197 196.966 569(4)	mercury Hg 80 196, 198, 199, 200, 201, 202, 204 200.59(2)	thallium Tl 81 203, 205 [204.382; 204.385]	lead Pb 82 204, 206, 207, 208 207.2(1)	bismuth Bi 83 209 208.980 40(1)	polonium Po 84	astatine At 85	radon Rn 86
francium Fr 87	radium Ra 88	89 - 103 actinoids	rutherfordium Rf 104	dubnium Db 105	seaborgium Sg 106	bohrium Bh 107	hassium Hs 108	meitnerium Mt 109	darmstadtium Ds 110	roentgenium Rg 111	copernicium Cn 112	ununtrium Uut 113	ununquadium Uuq 114	ununpentium Uup 115	ununhexium Uuh 116	ununseptium Uus 117	ununoctium Uuo 118

lanthanum La 57 138, 139 138.905 47(7)	cerium Ce 58 136, 138, 140, 142 140.116(1)	praseodymium Pr 59 141 140.907 65(2)	neodymium Nd 60 142, 143, 144, 145, 146, 148, 150 144.242(3)	promethium Pm 61	samarium Sm 62 144, 147, 148, 149, 150, 152, 154 150.36(2)	europium Eu 63 151, 153 151.964(1)	gadolinium Gd 64 152, 154, 155, 156, 157, 158, 160 157.25(3)	terbium Tb 65 159 158.925 35(2)	dysprosium Dy 66 156, 158, 160, 161, 162, 163, 164 162.500(1)	holmium Ho 67 165 164.930 32(2)	erbium Er 68 162, 164, 166, 167, 168, 170 167.259(3)	thulium Tm 69 169 168.934 21(2)	ytterbium Yb 70 168, 170, 171, 172, 173, 174, 176 173.054(5)	lutetium Lu 71 175, 176 174.9668(1)
actinium Ac 89	thorium Th 90 232 232.038 06(2)	protactinium Pa 91 231 231.035 88(2)	uranium U 92 234, 235, 238 238.028 91(3)	neptunium Np 93	plutonium Pu 94	americium Am 95	curium Cm 96	berkelium Bk 97	californium Cf 98	einsteinium Es 99	fermium Fm 100	mendelevium Md 101	nobelium No 102	lawrencium Lr 103

International Year of CHEMISTRY 2011

IUPAC Periodic Table of the Isotopes

The world that surrounds us, including the water that we drink and the air that we breathe, is mostly made of stable isotopes. The IUPAC Periodic Table of the Isotopes is intended to familiarize students and teachers with the existence of isotopes of chemical elements. The more familiar Periodic Table of the Elements found in most chemistry text books and on classroom walls illustrates important patterns of chemical behavior that are related to systematic variations in electronic configurations and atomic weights. The Periodic Table of the Isotopes highlights several categories of elements that are differentiated by the existence or non-existence of stable isotopes and the impact of the variation in stable isotope amounts on the atomic weight. For each element, the number of stable isotopes and their mass numbers are illustrated with colored pie charts; the relative amount of each stable isotope (called the isotopic abundance) is indicated by the size of the pie slice for that mass number. The table shows the current standard atomic weight for each element with its measured uncertainty in the last digit, or in some cases as an upper and lower bound.



Four of the elements in IUPAC's new periodic table of the isotopes for the educational community with stable isotopic abundances shown as pie diagrams (from left to right): Element (chlorine) whose standard atomic weight is not a constant of nature and is an interval. Element (mercury) whose standard atomic weight is not a constant of nature and is not an interval. Element (arsenic) whose standard atomic weight is a constant of nature because it has one stable isotope. Element (americium) that has no stable isotopes and thus no standard atomic weight.

Isotopes in Everyday Life

A more expanded "interactive" version of the IUPAC Periodic Table of the Isotopes is being developed which highlights applications of isotopes (both stable and unstable) of each chemical element and their practical uses in science and everyday life. Some types of isotope applications include forensics, geochronology, earth-system science, environment and human health science, and medical diagnosis and treatment. Useful unstable or radioactive isotopes (also called radio-isotopes) include technetium-99 (^{99}Tc) for imaging the internal organs of the human body for medical diagnosis; americium-241 (^{241}Am) for activating the alarm in smoke detectors; and carbon-14 (^{14}C) for answering questions such as "how long since the last Ice Age" and "how old is the Shroud of Turin." Useful stable isotopes include boron-10 (^{10}B) used in boron neutron capture therapy for treating brain tumors and carbon-13 and carbon-12 (^{13}C/^{12}C) or oxygen-18 and oxygen-16 (^{18}O/^{16}O) to detect performance-enhancing drug use in sports, authenticity of foods, effects of climate change, and origins of contaminants in the environment. Visit www.ciaaw.org for more details.

Isotopic Abundances and Standard Atomic Weights

Each atom of every element has protons and neutrons in its center (called the nucleus):

- The number of protons in each atom (i.e., the ***atomic number,*** symbol *Z*) determines the *chemical properties* of that atom. All atoms of a given element have the same number of protons (e.g., carbon atoms have 6 protons, while all uranium atoms have 92 protons).
- The number of neutrons (symbol *N*) in an atom of a given element may vary. Atoms of a given element which have different numbers of neutrons are called ***isotopes***.
- The total number of protons and neutrons (*Z* + *N*) in a given isotope is called the ***mass number***.

Isotopes may be stable or unstable. The unstable isotopes are also called radio-isotopes and will decay over time into another isotope of the same or a different element. The stable isotopes of each element and their mass numbers appear on each element cell of the Table in a pie chart, where each mass number is indicated around the outside of the pie. The relative amount of each stable isotope in a given element (called the ***isotopic abundance***) is approximately indicated by the size of the slice of the pie assigned to each mass number.

Some elements have no stable isotopes and therefore no mass numbers; these elements are indicated in white on the Table. Other elements have only one stable isotope and a single mass number and they are indicated in blue. The remaining elements have more than one stable isotope and mass number; these elements are indicated in either yellow or pink.

The atomic weight of an element is calculated from the sum of the products of the atomic mass[1] and the isotopic abundance[2] of each stable isotope of that element. The **Standard Atomic Weight** is the recommended value that can apply to all samples of a given element. Consider the simplified calculation for the case of carbon (all of whose isotopes have 6 protons since its atomic number is 6). Carbon has 2 stable isotopes of mass number 12 (abbreviated as ^{12}C; corresponding to an atom with 6 protons and 6 neutrons) and mass number 13 (^{13}C; corresponding to an atom with 6 protons and 7 neutrons). The atomic mass of each isotope can be approximated by its mass number, $^{12}\mathrm{C} \approx 12$ and $^{13}\mathrm{C} \approx 13$. Natural carbon is a mixture of ^{12}C and ^{13}C atoms with approximate isotopic abundances of 99% and 1%, respectively. The approximate atomic weight for this sample of carbon would be $12 \times 0.99 + 13 \times 0.01 = 12.01$.

For any element that has two or more stable isotopes, there is always the possibility that the relative amounts of stable isotopes may vary in various samples of that element found in nature. Using the above example, let us assume that another sample of carbon is made up of 98% ^{12}C and 2% ^{13}C. This sample of carbon has an approximate atomic weight of $12 \times 0.98 + 13 \times 0.02 = 12.02$. Thus, natural isotopic variation for an element can have an effect on the element's atomic weight value. For 10 such elements, the Standard Atomic Weight assigned by IUPAC is given as upper and lower bounds (called an interval)[3,4] written in brackets (e.g., for chlorine, it is [35.446; 35.457]). These elements are indicated in pink on the Table. Those elements for which no such assessments have been made or completed yet are indicated in yellow and their Standard Atomic Weights are given with an uncertainty in parentheses [e.g., for mercury, 200.59(2) is a contracted notation of 200.59 +/- 0.02].

References

1. G. Audi, A.H. Wapstra, and C. Thibault, *Nuclear Physics A* **729**, 337–676 (2003)
2. M. Berglund, M.E. Wieser, *Pure Appl. Chem.* **83**, 397–410 (2011)
3. M.E. Wieser and T.B. Coplen, *Pure Appl. Chem.* **83**, 359–396 (2011).
4. T.B. Coplen and N.E. Holden, *Chem. Int.* **33(2)**, 10–15 (2011).

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