

CHEMICA

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ELEMENTS—LIST BY SYMBOL

Berzelius invented modern chemical notation, replacing the disastrous hieroglyphics handed down from the alchemists. "If the first two letters be common to two metals, I shall use both the initial letter and the first letter they have not in common." He was speaking of their Latin names, of course.

Ac	89	Actinium	Kr	36	Krypton	Tb	65	Terbium
Ag	47	Silver	La	57	Lanthanum	Tc	43	Technetium
Al	13	Aluminum	Li	3	Lithium	Te	52	Tellurium
Am	95	Americium	Lr	103	Lawrencium	Th	90	Thorium
Ar	18	Argon	Lu	71	Lutetium	Ti	22	Titanium
As	33	Arsenic	Lv	116	Livermorium	Tl	81	Thallium
At	85	Astatine	Mc	115	Moscovium	Tm	69	Thulium
Au	79	Gold	Md	101	Mendelevium	Ts	117	Tennessee
B	5	Boron	Mg	12	Magnesium	U	92	Uranium
Ba	56	Barium	Mn	25	Manganese	V	23	Vanadium
Be	4	Beryllium	Mo	42	Molybdenum	W	74	Wolfram
Bh	107	Bohrium	Mt	109	Meitnerium	Xe	54	Xenon
Bi	83	Bismuth	N	7	Nitrogen	Y	39	Yttrium
Bk	97	Berkelium	Na	11	Sodium	Yb	70	Ytterbium
Br	35	Bromine	Nb	41	Niobium	Zn	30	Zinc
C	6	Carbon	Nd	60	Neodymium	Zr	40	Zirconium
Ca	20	Calcium	Ne	10	Neon			
Cd	48	Cadmium	Nh	113	Nihonium			
Ce	58	Cerium	Ni	28	Nickel			
Cf	98	Californium	No	102	Nobelium			
Cl	17	Chlorine	Np	93	Neptunium			
Cm	96	Curium	O	8	Oxygen			
Cn	112	Copernicium	Og	118	Oganesson			
Co	27	Cobalt	Os	76	Osmium			
Cr	24	Chromium	P	15	Phosphorus			
Cs	55	Cesium	Pa	91	Protactinium			
Cu	29	Copper	Pb	82	Lead			
Db	105	Dubnium	Pd	46	Palladium			
Ds	110	Darmstadtium	Pm	61	Promethium			
Dy	66	Dysprosium	Po	84	Polonium			
Er	68	Erbium	Pr	59	Praseodymium			
Es	99	Einsteinium	Pt	78	Platinum			
Eu	63	Europium	Pu	94	Plutonium			
F	9	Fluorine	Ra	88	Radium			
Fe	26	Iron	Rb	37	Rubidium			
Fl	114	Flerovium	Re	75	Rhenium			
Fm	100	Fermium	Rf	104	Rutherfordium			
Fr	87	Francium	Rg	111	Roentgenium			
Ga	31	Gallium	Rh	45	Rhodium			
Gd	64	Gadolinium	Rn	86	Radon			
Ge	32	Germanium	Ru	44	Ruthenium			
H	1	Hydrogen	S	16	Sulfur			
Hs	108	Hassium	Sb	51	Antimony			
He	2	Helium	Sc	21	Scandium			
Hf	72	Hafnium	Se	34	Selenium			
Hg	80	Mercury	Sg	106	Seaborgium			
Ho	67	Holmium	Si	14	Silicon			
I	53	Iodine	Sm	62	Samarium			
In	49	Indium	Sn	50	Tin			
Ir	77	Iridium	Sr	38	Strontium			
K	19	Potassium	Ta	73	Tantalum			

ELEMENTS—LIST BY ATOMIC NUMBER

Electronic configurations for the ground state neutral gaseous atom, from Mark Winter, *WebElements*; checked against Atkins for 1–30 and against Gillespie et al. for 1–103 (note discrepancies at 43 and 103).

1 Hydrogen H	$1s^1$	52 Tellurium Te	$[\text{Kr}]5s^24d^{10}5p^4$
2 Helium He	$1s^2$	53 Iodine I	$[\text{Kr}]5s^24d^{10}5p^5$
3 Lithium Li	$[\text{He}]2s^1$	54 Xenon Xe	$[\text{Kr}]5s^24d^{10}5p^6$
4 Beryllium Be	$[\text{He}]2s^2$	55 Cesium Cs	$[\text{Xe}]6s^1$
5 Boron B	$[\text{He}]2s^22p^1$	56 Barium Ba	$[\text{Xe}]6s^2$
6 Carbon C	$[\text{He}]2s^22p^2$	57 Lanthanum La	$[\text{Xe}]6s^25d^1$
7 Nitrogen N	$[\text{He}]2s^22p^3$	58 Cerium Ce	$[\text{Xe}]6s^25d^14f^1$
8 Oxygen O	$[\text{He}]2s^22p^4$	59 Praseodymium Pr	$[\text{Xe}]6s^24f^3$
9 Fluorine F	$[\text{He}]2s^22p^5$	60 Neodymium Nd	$[\text{Xe}]6s^24f^4$
10 Neon Ne	$[\text{He}]2s^22p^6$	61 Promethium Pm	$[\text{Xe}]6s^24f^5$
11 Sodium Na	$[\text{Ne}]3s^1$	62 Samarium Sm	$[\text{Xe}]6s^24f^6$
12 Magnesium Mg	$[\text{Ne}]3s^2$	63 Europium Eu	$[\text{Xe}]6s^24f^7$
13 Aluminum Al	$[\text{Ne}]3s^23p^1$	64 Gadolinium Gd	$[\text{Xe}]6s^25d^14f^7$
14 Silicon Si	$[\text{Ne}]3s^23p^2$	65 Terbium Tb	$[\text{Xe}]6s^24f^9$
15 Phosphorus P	$[\text{Ne}]3s^23p^3$	66 Dysprosium Dy	$[\text{Xe}]6s^24f^{10}$
16 Sulfur S	$[\text{Ne}]3s^23p^4$	67 Holmium Ho	$[\text{Xe}]6s^24f^{11}$
17 Chlorine Cl	$[\text{Ne}]3s^23p^5$	68 Erbium Er	$[\text{Xe}]6s^24f^{12}$
18 Argon Ar	$[\text{Ne}]3s^23p^6$	69 Thulium Tm	$[\text{Xe}]6s^24f^{13}$
19 Potassium K	$[\text{Ar}]4s^1$	70 Ytterbium Yb	$[\text{Xe}]6s^24f^{14}$
20 Calcium Ca	$[\text{Ar}]4s^2$	71 Lutetium Lu	$[\text{Xe}]6s^25d^14f^{14}$
21 Scandium Sc	$[\text{Ar}]4s^23d^1$	72 Hafnium Hf	$[\text{Xe}]6s^25d^24f^{14}$
22 Titanium Ti	$[\text{Ar}]4s^23d^2$	73 Tantalum Ta	$[\text{Xe}]6s^25d^34f^{14}$
23 Vanadium V	$[\text{Ar}]4s^23d^3$	74 Tungsten W	$[\text{Xe}]6s^25d^44f^{14}$
24 Chromium Cr	$[\text{Ar}]4s^13d^5$	75 Rhenium Re	$[\text{Xe}]6s^25d^54f^{14}$
25 Manganese Mn	$[\text{Ar}]4s^23d^5$	76 Osmium Os	$[\text{Xe}]6s^25d^64f^{14}$
26 Iron Fe	$[\text{Ar}]4s^23d^6$	77 Iridium Ir	$[\text{Xe}]6s^25d^74f^{14}$
27 Cobalt Co	$[\text{Ar}]4s^23d^7$	78 Platinum Pt	$[\text{Xe}]6s^15d^94f^{14}$
28 Nickel Ni	$[\text{Ar}]4s^23d^8$	79 Gold Au	$[\text{Xe}]6s^15d^{10}4f^{14}$
29 Copper Cu	$[\text{Ar}]4s^13d^{10}$	80 Mercury Hg	$[\text{Xe}]6s^25d^{10}4f^{14}$
30 Zinc Zn	$[\text{Ar}]4s^23d^{10}$	81 Thallium Tl	$[\text{Xe}]6s^25d^{10}4f^{14}6p^1$
31 Gallium Ga	$[\text{Ar}]4s^23d^{10}4p^1$	82 Lead Pb	$[\text{Xe}]6s^25d^{10}4f^{14}6p^2$
32 Germanium Ge	$[\text{Ar}]4s^23d^{10}4p^2$	83 Bismuth Bi	$[\text{Xe}]6s^25d^{10}4f^{14}6p^3$
33 Arsenic As	$[\text{Ar}]4s^23d^{10}4p^3$	84 Polonium Po	$[\text{Xe}]6s^25d^{10}4f^{14}6p^4$
34 Selenium Se	$[\text{Ar}]4s^23d^{10}4p^4$	85 Astatine At	$[\text{Xe}]6s^25d^{10}4f^{14}6p^5$
35 Bromine Br	$[\text{Ar}]4s^23d^{10}4p^5$	86 Radon Rn	$[\text{Xe}]6s^25d^{10}4f^{14}6p^6$
36 Krypton Kr	$[\text{Ar}]4s^23d^{10}4p^6$	87 Francium Fr	$[\text{Rn}]7s^1$
37 Rubidium Rb	$[\text{Kr}]5s^1$	88 Radium Ra	$[\text{Rn}]7s^2$
38 Strontium Sr	$[\text{Kr}]5s^2$	89 Actinium Ac	$[\text{Rn}]7s^26d^1$
39 Yttrium Y	$[\text{Kr}]5s^24d^1$	90 Thorium Th	$[\text{Rn}]7s^26d^2$
40 Zirconium Zr	$[\text{Kr}]5s^24d^2$	91 Protactinium Pa	$[\text{Rn}]7s^26d^15f^2$
41 Niobium Nb	$[\text{Kr}]5s^14d^4$	92 Uranium U	$[\text{Rn}]7s^26d^15f^3$
42 Molybdenum Mo	$[\text{Kr}]5s^14d^5$	93 Neptunium Np	$[\text{Rn}]7s^26d^15f^4$
43 Technetium Tc	$[\text{Kr}]5s^14d^6$ (Gill.: $[\text{Kr}]5s^24d^5$)	94 Plutonium Pu	$[\text{Rn}]7s^25f^6$
44 Ruthenium Ru	$[\text{Kr}]5s^14d^7$	95 Americium Am	$[\text{Rn}]7s^25f^7$
45 Rhodium Rh	$[\text{Kr}]5s^14d^8$	96 Curium Cm	$[\text{Rn}]7s^26d^15f^7$
46 Palladium Pd	$[\text{Kr}]4d^{10}$	97 Berkelium Bk	$[\text{Rn}]7s^25f^9$
47 Silver Ag	$[\text{Kr}]5s^14d^{10}$	98 Californium Cf	$[\text{Rn}]7s^25f^{10}$
48 Cadmium Cd	$[\text{Kr}]5s^24d^{10}$	99 Einsteinium Es	$[\text{Rn}]7s^25f^{11}$
49 Indium In	$[\text{Kr}]5s^24d^{10}5p^1$	100 Fermium Fm	$[\text{Rn}]7s^25f^{12}$
50 Tin Sn	$[\text{Kr}]5s^24d^{10}5p^2$	101 Mendelevium Md	$[\text{Rn}]7s^25f^{13}$
51 Antimony Sb	$[\text{Kr}]5s^24d^{10}5p^3$	102 Nobelium No	$[\text{Rn}]7s^25f^{14}$

103	Lawrencium Lr	$[\text{Rn}]7s^25f^{14}7p^1$ * (Gill.: $[\text{Rn}]7s^26d^{15}f^{14}$)
104	Rutherfordium Rf	$[\text{Rn}]7s^26d^{25}f^{14}$ *
105	Dubnium Db	$[\text{Rn}]7s^26d^{35}f^{14}$ *
106	Seaborgium Sg	$[\text{Rn}]7s^26d^{45}f^{14}$ *
107	Bohrium Bh	$[\text{Rn}]7s^26d^{55}f^{14}$ *
108	Hassium Hs	$[\text{Rn}]7s^26d^{65}f^{14}$
109	Meitnerium Mt	$[\text{Rn}]7s^26d^{75}f^{14}$ *
110	Darmstadtium Ds	$[\text{Rn}]7s^16d^{95}f^{14}$ *
111	Roentgenium Rg	$[\text{Rn}]7s^16d^{105}f^{14}$ *
112	Copernicium Cn	$[\text{Rn}]7s^26d^{105}f^{14}$ *
113	Nihonium Nh	
114	Flerovium Fl	$[\text{Rn}]7s^26d^{105}f^{14}7p^2$ *
115	Moscovium Mc	
116	Livermorium Lv	$[\text{Rn}]7s^26d^{105}f^{14}7p^4$ *
117	Tennessine Ts	
118	Oganesson Og	

Notes:

As of 6/01, no element heavier than Hs (108) has had its chemical properties analyzed.

- 103 Electron configuration tentative.
- 104 Electron configuration tentative.
- 105 Electron configuration tentative, based on tungsten.
- 106 Electron configuration tentative, based on tantalum.
- 107 Electron configuration tentative, based on rhenium.
- 109 Electron configuration tentative, based on iridium.
- 110 Electron configuration tentative, based on platinum.
- 111 Electron configuration tentative, based on gold.
- 112 Electron configuration tentative, based on mercury.
- 114 Electron configuration tentative, based on lead.
- 116 Electron configuration tentative, based on polonium.

ELEMENTS: ALPHABETICAL NOTES

- a) The atomic masses of many elements are not invariant but depend on the origin and treatment of the material; the values given here apply to elements as they exist naturally on the earth and to certain artificial elements.
- b) For these radioactive elements the mass given is that for the longest-lived isotope.
- c) Atomic masses for these radioactive elements cannot be quoted precisely without knowledge of the origin of the elements; the value given is the atomic mass number of the isotope of that element of longest known half-life.
- d) The value given is the atomic mass number of the most stable or most common isotope. (From [web table].)

Sources: Gillespie, et al.; Atkins, *Web Elements*; miscellaneous reading.

As of 6/01, no element heavier than Hs (108) has had its chemical properties analyzed. As of 2/04, the JINR discoveries of elements 113–116 (& 117?) have yet to be confirmed by duplication at other laboratories.

Element	Sym.	No.	Atomic Mass ^a	Molar Mass (g mol ⁻¹)
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Actinium	Ac	89	227.0278^b	
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Discovered 1899. Named from Gk. aktinos = ray. Occurs naturally as a decay product of uranium and thorium. "Very limited commercial or scientific application." 26 known isotopes.

Aluminum	Al	13	26.981	54
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Iron, oxygen, silicon, and magnesium are the most abundant elements of Earth, followed by sulfur, nickel, calcium, and aluminum.

Melts at 660°C (1214°F).

V. Gillespie 783 on the discovery of an economical process for making Al. Until then, it was worth more than gold. A Frenchman, Héroult, made the same discovery as Hall at about the same time; both were very young, and the same age.

Lindsley: "Unlike the early processes for recovering other metals, practical recovery of aluminum was not achieved until 1886 when the genius of Charles Martin Hall found a way to produce aluminum by electrolysis. This is an odd fact, since one twelfth of the earth's crust is estimated to contain aluminum, and it is one of the most common substances in nature. Bauxite ore, containing aluminum hydroxide, cannot be smelted like iron ore since aluminum is a very active lender of electrons and the exchange process with carbon used for iron ore will not work. It long seemed apparent that bauxite could be returned to its metallic aluminum state if some way could be found to replace the electrons the aluminum had loaned to form aluminum oxide. Hall found that a white mineral, cryolite, when heated and melted, acts as a solvent for the alumina and provides an electrolyte. By immersing large carbon electrodes in a boxlike cell, also lined with carbon, and passing a heavy current through the contents, the necessary melting takes place, the electrons needed are added to the aluminum oxide, and the metal collects at the bottom of the cell. Recent technology has developed other solvent materials, but the process still depends on high levels of electrical power. Some texts say it takes 12KwHrs of electrical energy to produce 1 pound of aluminum. This is the reason that aluminum can be recycled economically."

Stwertka: "The production of aluminum consumes about 5 percent of all the electricity used in the United States today." A good conductor of electricity, though with only 65% of the capacity of copper; its light weight makes it useful for some high-voltage transmission lines. It is soft, but can be greatly strengthened by alloying it with small amounts of copper or magnesium. Reactive, but once an oxide layer forms further corrosion is prevented, "so it is usually considered corrosion-resistant."

Aluminum was the material of the projectile sent to the Moon by the Gun Club in Jules Verne's *De la terre à la lune* (1863); the physical and economic aspects of the metal are discussed in ch. 7 of that work.

Levine 5: "Titanium and niobium, and even aluminum, can be toned to a whole rainbow of colors by deft application of heat, electricity, and chemical reagents." Toned Ti, Nb, and Al are used in knife handles.

Americium	Am	95	(243)^c	
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Discovered 1944 by a team led by Glenn Seaborg.

14 known isotopes. Am-241 is produced in large quantities in nuclear reactors; used in smoke detectors and as an X-ray source.

Element	Sym.	No.	Atomic Mass ^a	Molar Mass (g mol ⁻¹)
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Antimony	Sb	51	121.75	
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The name is from the Greek *anti* + *monos* = "not alone". (*Web Elements*, without explanation.) The symbol is from the Latin *stibium*. (*LS*, Tucker, s.v.: an Egyptian word (Tucker), coming via Greek, for "sulphuret of antimony", a cosmetic and medication. The ore is called stibnite. The substance was known anciently, but not [distinguished as a metal until the 1600s]; the alchemists thought the metal was lead. However, according to Jaffe 154, the element was described, "rather fancifully", by Basil Valentine in 1492.

Melts at 630°C (1166°F). Included in type metal to increase hardness and to allow for a sharper casting than Pb alone could make. Alloys in type metal also lower melting point to a temperature lower than the melting points of any of the pure metals. Also a component of pewter.

Argon	Ar	18	39.948	
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Abundant in the atmosphere. (More abundant, in fact than CO₂.) "Most of the argon in the atmosphere comes from the radioactive decay of potassium in the Earth's crust." (SN 159.116.) Discovered by William Ramsay in the 1890s, and named from a Greek word meaning "lazy", on account of its non-reactivity. It was the first of the noble gases to be discovered, and a new group (18) had to be created for it on the periodic table.

Nitrogen is used commercially as a food preservative, pumped into packaging to replace air (and specifically oxygen). Argon, already used for museum preservation, is now beginning to be used for food; it is heavier than N; pouring like water; more expensive than N, but more efficient. SN 9/8/01 160.159.

Rayleigh at first wanted to name it "aeron", but when he used that name the reaction tended to be "When may we expect Moses?" (Jaffe.)

Arsenic	As	33	74.9216	
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SN 159.164 (3/17/01), article on the effects of environmental arsenic on health, as carcinogen and endocrine disrupter. "Large geologic deposits of arsenic exist in Asia, South America, and several U.S. states." Arsenic in mineral form has a garlic odor when heated. (Zim & Shaffer, p. 27.)

From L arsenicum = orpiment. Used in the insecticide "Paris green".

Stwertka: discovered in 1250 by Albertus Magnus. Presumably he identified it as a distinct substance. Jaffe 154 seems to make it a much later discovery, but before the late 1700s.

Astatine	At	85	(210)^c	
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Named from Gk astatos, unstable. 20 known isotopes, all radioactive. The longest-lived has a half-life of 8.3 hours. First made in 1940. Occurs naturally as a product of radioactive decay of uranium and thorium. Little is known of its chemistry, which is presumed to resemble that of the other halogens, esp, iodine, just above it.

Barium	Ba	56	137.33	
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Discovered by Humphry Davy in 1808.

Berkelium	Bk	97	(247)^c	
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Synthesized 1949 by Glenn Seaborg, Albert Ghiorso, et al., in Berkeley.

15 known isotopes. Most stable is Bk-249. First made was Bk-243.

Element	Sym.	No.	Atomic Mass ^a	Molar Mass (g mol ⁻¹)
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Beryllium **Be** **4** **9.012** **18**

Bismuth **Bi** **83** **208.9804**

Known since the early 1400s, but often confused with lead and tin. Name derived (manner not specified by Stwertka) from German *weisse masse*, white mass. Apparently identified [as a separate element] in 1753, though the history is not clear. Jaffe 154 says it was discussed by Agricola in *De Re Metallica* (1530).

Expands when it changes from liquid to solid; thus alloyed with other metals to add dimensional stability.

Bohrium **Bh** **107** **(262)^d**

Synthesis was announced in 1976 by Dubna (claim rejected), and in 1981 by Darmstadt (claim accepted, confirmed in 1992. Chemical and physical properties unknown.

The name nielsbohrium was also proposed for this element. The name Bohrium was confirmed in 1997.

Boron **B** **5** **[10.806; 10.821] (old: 10.81)**

Not found pure.

Bromine **Br** **35** **79.904**

Discovered by Antoine-Jérôme Balard in 1826. Named from the Greek *bromos* = stench. (It produces acrid fumes when exposed to air.) Notes Atkins, "A pleasant fragrance is rarely an attribute of the elements." Discovered in 1826. Toxic. Sodium bromide was used as a mild sedative in the late 1800s–early 1900s.

Cadmium **Cd** **48** **112.41**

Chemical properties strongly resemble those of zinc, just above it in the periodic table. Commonly found with zinc. Toxic. Discovered in 1817.

Calcium **Ca** **20** **40.08**

Iron, oxygen, silicon, and magnesium are the most abundant elements of Earth, followed by sulfur, nickel, calcium, and aluminum.

First produced in 1808 by Humphrey Davy, by electrolysis of its compounds. Name is from Latin *calx* = lime.

Californium **Cf** **98** **(249)^e**

Synthesized 1950 by Glenn Seaborg, Albert Ghiorso, et al., in Berkeley.

15 known isotopes: First made was Cf-245. Cf-252 spontaneously emits neutrons, which gives it some lab and field applications, despite its scarcity, extreme radioactivity, and half-life of 2.65 yrs.

Carbon **C** **6** **[12.0096; 12.0116] (old: 12.011)**

Carbon is the third most abundant element in the universe, after hydrogen and helium. Primordially formed by the fusing of He in the cores of collapsing stars.

Carbon and tungsten apparently have higher melting points than any other elements.

Stwertka: "Carbon owes its central position in the organic world to the ability of its atoms to link up with other carbon atoms to form long chains that are either straight or branched. These chains act as a backbone to which other elements are attached, yielding an almost endless number of possible carbon-containing molecules." These include DNA.

Carbon is found in several natural forms, called 'allotropes', including diamond, graphite, and synthetic allo-

Element	Sym.	No.	Atomic Mass ^a	Molar Mass (g mol ⁻¹)
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tropes, buckyballs and nanotubes. Single sheets of graphene (of which graphite is made), one atom thick “two-dimensional crystals”, also have interesting technological possibilities.

Cerium **Ce** **58** **140.12**

Named for the asteroid Ceres, discovered two years previous to the element's discovery in 1803. (Cf. palladium.) One of the most abundant of the rare earths, and very reactive. Has industrial uses.

Cesium **Cs** **55** **132.9054**

Also caesium. Named from the Latin *caesius* = sky blue, not from the color of the element, but from that of the flame when it is burned. Melts at 28.5°C (83.3°F). Much (or most?) Cs is a by-product of nuclear reactors, being extracted from the spent fuel. Discovered in 1860 by Kirchoff and Bunsen.

Cesium-133 is the only naturally occurring isotope. It is used in cesium clocks.

Chlorine **Cl** **17** **[35.446; 35.457] (old: 35.453)**

Discovered by Karl Scheele in 1774, named and recognized as an element by Humphry Davy in 1810. Named from the Greek *chloros* = yellowish green, its color.

Chromium **Cr** **24** **51.996**

Discovered 1797 by Vauquelin, isolated in a newly-discovered natural orange pigment from the Urals. Named from the Greek *chroma* = color, because its salts take on a rainbow of colors. Trace amounts of its compounds color many gemstones. Used in many dyes and pigments, notably the best yellow known at the time, and an excellent green. Stwertka: “When exposed to air, chromium forms an invisible oxide that makes the metal extremely resistant to corrosion.”

Cobalt **Co** **27** **58.9332**

From the German *Kobold*, a gremlin blamed for mishaps in mines, because it made difficult the refining of copper from ore. (Cf. nickel.) Discovered 1742 (or 1739, isolated by Swedish chemist Georg Brandt). L. cobaltum seen.

Easily magnetized.

Columbium

Original name of Niobium; still occasionally seen.

Copernicium **Cn** **112** **(277)^d**

Copernicium—one atom of it, which decayed within 280 milliseconds—was first created in 1996 by the GSI Helmholtz Centre for Heavy Ion Research near Darmstadt, Germany. It was identified by means of its decay chains.

Known isotopes: . The most stable known isotope, copernicium-285, has a half-life of approximately 29 seconds. Cn-277 was the first discovered.

As of 6/01, no element heavier than Hs (108) has had its chemical properties analyzed.

Copper **Cu** **29** **63.546**

The name derives from that of Cyprus, an important ancient source of the metal. Zinc is alloyed with copper to form brass, tin to form bronze.

The coating of green oxidation prevents further oxidation of the underlying metal.

Cops, or coppers, are so called from the copper buttons once worn on police uniforms somewhere.

Element	Sym.	No.	Atomic Mass ^a	Molar Mass (g mol ⁻¹)
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Curium **Cm** **96** **(247)^c**

Discovered 1944 by Glenn Seaborg, Albert Ghiorso, et al.

14 known isotopes:

Cm-242 (h/l 163 days, the first discovered).

Cm-247, the most stable (h/l 16 million years).

Cm-242 and Cm-244, of which large quantities can be made in nuclear reactors, useful as power sources in batteries for special applications, e.g. spacecraft, pacemakers, remote navigation buoys.

Darmstadtium Ds **110** **(269)^d**

Discovered 1994, in Darmstadt.

Known isotopes: 15. Most stable: Ds-281, h/l 1.1 minute. Ds-269, h/l 270 millionths of a second.

A possible production of a single atom of element 110 was reported in 1994 (Atkins p. 26). As of 6/01, no element heavier than Hs (108) has had its chemical properties analyzed.

W: "It is an extremely radioactive synthetic element. The most stable known isotope, darmstadtium-281, has a half-life of approximately 10 seconds. Darmstadtium was first created in 1994 by the GSI Helmholtz Centre for Heavy Ion Research near the city of Darmstadt, Germany, after which it was named."

Dubnium **Db** **105** **(262)^d**

Extremely short-lived. Created using particle accelerators. Named after Dubna, a research site in the U.S.S.R. First claim of discovery by Dubna, 1967; subsequent synthesis at Berkeley, 1970, and the name Hahnium, proposed by Berkeley, was accepted until 1997. The name joliotium was also proposed for element 105. Chemical and physical properties unknown. 104, 105; cf. 106 Sg: Properties do not seem consistent with its place on the PT.

Known isotopes: 5. Most stable: Db-262, h/l 34 sec.

Dysprosium **Dy** **66** **162.50**

Discovered in 1886. Named from the Greek *dysprositos* = "hard to get at", apparently because it was very difficult to isolate.

Einsteinium **Es** **99** **(252)^c**

Es-253 discovered by Ghiorso et al., 1952, in the debris of the first H-bomb test.

16 known isotopes. Most stable: Es-252.

Erbium **Er** **68** **167.26**

Discovered 1843. Named (like three other elements) from Ytterby, a small town in Sweden, where a variety of minerals have been found, among them yttria and erbia. Among other uses, added to glass and glazes to color them pink.

Europium **Eu** **63** **151.96**

One of the rarest rare earths. Discovered in 1901. Named perhaps in deliberate response to the Scandinavian near-monopoly on rare-earth-element names (four named after Ytterby, one named after Stockholm, one named after the Finn Gadolin, one named after Thule).

Fermium **Fm** **100** **(257)^c**

Like Einsteinium, Fm -252 was discovered by Ghiorso et al., 1952, in the debris of the first H-bomb test.

18 known isotopes. Most stable: Fm-257.

Element	Sym.	No.	Atomic Mass ^a	Molar Mass (g mol ⁻¹)
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Flerovium	Fl	114	(289)^d	
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Discovered at Dubna, 1999—one atom—by a team led by Yuri Oganessian.

Known isotopes: . Most stable: the one discovered was relatively stable, with a h/l of est. 30 sec.

V. SN 6/30/12.10. As of 6/01, no element heavier than Hs (108) has had its chemical properties analyzed.

Fluorine	F	9	18.998	403
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First produced in its pure state by Henri Moissan in 1886; he won the Nobel Prize for it. Highly reactive, not found free in nature. It is commercially prepared from fluorspar. The name probably derives from the use of fluorite as a flux.

Francium	Fr	87	(223)^c	
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Discovered in 1930. Named for France. 30 known isotopes; Fr-223, the longest-lived, has a half life of 21 minutes and occurs in nature as a product of the radioactive decay of uranium and thorium. It is estimated that Earth's crust contains about 1 ounce of it.

Gadolinium	Gd	64	157.25	
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Discovered in 1886. Named for the Finnish chemist Johan Gadolin, who did much work on the rare earths. Loses its magnetism at 17°C, room temperature.

Gallium	Ga	31	69.72	
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First isolated in 1875. (Discovered 1874 per Gillespie et al.) Its existence and properties had been predicted by Mendeleev in 1869, who called it eka-aluminum. (V. Jaffe 151.) Named for France, but with a Latin pun on the name of its discoverer, François Lecoq de Boisbaudran. Melts at 29.8°C (85.6°F)—but boils at 2,403°C. Like water, it expands when it freezes.

First found a use in laser diodes, such as those in CD players. Also a semiconductor that generates less heat than silicon; used in supercomputers. Obtained as a by-product in refining other metals, esp. aluminum.

Germanium	Ge	32	72.59	
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Discovered by the German chemist Clemens Winkler in 1886. (Discovered 1885 per Gillespie et al.) Its existence and properties had been predicted by Mendeleev (“eka-silicon”) in 1871. (V. Jaffe 152.) This discovery, after those of Gallium and Scandium, was the final proof, for those who needed it, that Mendeleev was right.) A semiconductor; doped germanium is used in microchips.

Gold	Au	79	196.9665	
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Chemically virtually inert. (But highly reactive in nanoparticle form.)

SN 2/18/17.11: Relativistic and quantum effects needed to explain properties of gold.

Hafnium	Hf	72	178.49	
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Named from *Hafnia*, Copenhagen, in honor of Niles Bohr. Predicted by Mendeleev and others, not discovered until 1923, using quantum theory of electron shells and subshells developed by Bohr. Its chemical properties are almost identical to those of zirconium, just above it in the periodic table, though it is less dense; they are difficult to isolate from one another. It also absorbs neutrons much better than Zr, and is used in nuclear control rods in some applications. Though not extremely rare (1/100,000 of the crust of earth), it is very expensive: the rods for a large reactor can cost \$1M total. It has few other applications.

Element	Sym.	No.	Atomic Mass ^a	Molar Mass (g mol ⁻¹)
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Hassium Hs 108 (223)^d

Extremely short-lived. First created in 1984, in Darmstadt, using particle accelerators. Named after the German state of Hesse. The name Hahnium was also proposed for this element.

SN 159.392(6/23/01): Hassium's chemistry studied for the first time, and its place in the periodic table confirmed. The sample ("at least six molecules") was created by colliding Cm-248 and Mg-26 in an accelerator. Hs has a half-life of 9 seconds. As of this writing, Hs is the heaviest element to have its chemistry studied.

Known isotopes: . Most stable: .

Hahnium—see Hassium. (After Otto Hahn.)

Helium He 2 4.002 60

Two protons and two neutrons. "Makes up about 25% of the universe", about 7% of all atoms" V. Pagels, *PS* pp. 252–6 on the formation of the primordial elements. First identified in 1868 by astronomer Norman Lockyer, in spectroscopic observations of a solar eclipse, and named accordingly for the sun. Isolated in 1895 by Ramsay. It exists naturally on Earth as a gas given off by uranium ore: U gives off He nuclei—alpha particles—as it decays. *NG* 6/28:"When chemistry, experimenting in laboratories, first made helium gas by breaking down uranium ores, it cost \$1,500 to \$2,200 a cubic foot. Now, at a Fort Worth extracting plant, helium is taken from natural gas for about three cents!" (Caption to picture of railcar carrying tanks of compressed helium.)

Hydrogen and helium are counted among the metals by astronomers: the category of "high-metal stars" is significant for the chemistry of planet formation. (*SN* 4/28/18.30.)

Holmium Ho 67 164.9304

Isolated and identified in 1886; spectral lines detected 1878. Named from *Holmia*, Stockholm.

Hydrogen H 1 [1.00784; 1.00811] (old: 1.007) 94

The valence of H is said to be 1, (exceptionally, despite its having only one electron) since it normally combines with at most one atom of *another* element. For this reason, H can be counted as part of Group 7A, whose elements have a valence of one. The nucleus of a H atom consists of a single proton.

Normally diatomic.

Hydrogen and helium are counted among the metals by astronomers: the category of "high-metal stars" is significant for the chemistry of planet formation. (*SN* 4/28/18.30.)

Isotopes: Deuterium (adds 1 neutron), Tritium (2 neutrons).

Discovered in the 1700s.

By far the most abundant element in the universe: 93% of all atoms. Scarce in Earth's atmosphere, though, since it easily escapes Earth's gravitational pull; Jupiter and Saturn have considerably more. V. Pagels, *PS* pp. 252–6 on the formation of the primordial elements. On the stellar mechanism by which molecules of H combine to produce both He and the massive amounts of energy that fuel the stars, v. Pagels, *PS* p. 32. Deuterium (given the symbol D; also called heavy hydrogen; has a neutron in addition to the proton in the nucleus) is the only stable isotope of the basic H atom. It occurs naturally in very small quantities. Unusually for an isotope, it has some notable chemical differences from the basic atom. There is one other isotope, Tritium (T), with two neutrons, unstable and radioactive, but with a relatively short half life, so that it does not accumulate. It occurs in nature because it is constantly produced by reactions with cosmic rays.

It is believed that small amounts of D and Li existed in the primordial universe, along with the prevalent H and He.

Native (gaseous) H is rarely found on Earth, except in a few pockets of gas trapped in rock formations. First recognized as an element by Henry Cavendish in 1766 (cf. Mach, *Sci. Mech.*, on the excitement caused by the identification of gases other than air, of which this was one of the first), but had been produced long before. Named for its production from water.

Indium **In** **49** **114.82**

Generally obtained as a by-product of zinc refining. Named from *indicum*, L for indigo, from its spectroscopic color.

Iodine **I** **53** **126.9045**

Named from the Greek *ioeides* = violet, the color of its solid and gas. Very reactive. Tincture of iodine, the familiar antiseptic, is a solution of 50% iodine in alcohol.

Iridium **Ir** **77** **192.22**

Discovered 1803. Named from the Greek *iris* = rainbow, because its compounds take on a rainbow of colors. A precious metal. Similar to its next neighbor Platinum, q.v. Found together with platinum and nickel. Alloyed with platinum for to add hardness.

Iron **Fe** **26** **55.847**

Iron, oxygen, silicon, and magnesium are the most abundant elements of Earth, followed by sulfur, nickel, calcium, and aluminum. Fe is the heaviest element formed by nuclear fusion in stars—Fe nuclei will not fuse to form heavier elements. “The formation of iron absorbs more energy than it releases.” (Heavier elements, up to U, can be created in the collapse of very massive stars. V. SN160.264, 10/27/01: certain isotopes thought to have been formed in supernovae may have come from stellar activity in young, Sun-like stars; not clear whether this includes isotopes heavier than Fe.)

Never found pure in nature: it has always already rusted. Since the rust crumbles off, the metal continues to oxidize. The iron in hemoglobin molecules bonds to oxygen, allowing it to be carried by blood cells.

It is the spacing of atoms in the metal that allows the electric properties common to all atoms to generate significant magnetic effects.

Melts at 1520°C (2768°F). (Grey cast iron melts at 2200°F; [the impurities lower the melting point].)

Joliotium—see Dubnium. (After Frédéric Joliot-Curie.)

Krypton **Kr** **36** **83.80**

Discovered along with other noble gases by William Ramsay in 1898, following his discovery of argon, the first known.

Lanthanum **La** **57** **138.9055**

Discovered 1839. From Gk *lanthanein*, to lie hidden, presumably because it, like the other rare earths (lanthanoid series) are difficult to isolate.

Lawrencium **Lr** **103** **(260)^c**

Discovered 1961 by Ghiorso et al. (Lw-258m h/l 4 seconds). Named for Ernest O. Lawrence of Berkeley, inventor of the cyclotron. A little analysis of its oxidation properties has been done, which suggests it is similar to other actinoid elements. Otherwise, little known about its properties.

Known isotopes: 8. Most stable: Lw-256, h/l 30 seconds.

Lead **Pb** **82** **207.2**

Known from Egypt ~5000. Melts at 327°C (621°F). The most important ore is galena, lead sulfide (PbS); native lead is rare. Mainly used now in U.S. as a component of lead storage batteries. Also common in solder. Compounds often used in paints and pigments, because insoluble. A cumulative poison, because

the body retains the lead. Crystal glass is made with lead; the glass has a high index of refraction, so it bends light at sharp angles, and is very sparkly when cut properly.

Many isotopes.

Lithium **Li** **3** **[6.938; 6.997] (old: 6.941)**

It is believed that small amounts of L existed in the primordial universe, along with the prevalent H and He, and small amounts of deuterium.

As with all alkali metals, extremely reactive; thus never found pure in nature.

Used for the positive terminal in batteries, and alloyed with aluminum for aerospace use.

Livermorium **Lv** **116** **(289)^d**

In 1999, researchers at Lawrence Berkeley National Laboratory reported creation of three atoms of element 118, which decayed into products including element 116, itself previously undiscovered. (*SN* 6/12/99, p. 372). The claim was retracted in 2001, but researchers at Dubna and Livermore “appear to have since created element 116 directly” (*SN* 160.68, 8/4/01)—this was in 12/2000. Confirmatory experiments succeeded in 2004 and 2006

Known isotopes: 4, all extremely unstable. Most stable: Lv-293, h/l 61 milliseconds. First made: Lv-292, decayed within 49 milliseconds.

As of 6/01, no element heavier than Hs (108) has had its chemical properties analyzed.

Lutetium **Lu** **71** **174.967**

One of the rarest of the rare-earth elements, and the hardest and heaviest. Discovered in 1907, by a French chemist and a German one. (There is an American claim for the same year.) The German wanted to name it cassiopium, after the constellation, and it is still sometimes referred to by this name in Germany. Stwertka notes no uses for it.

Magnesium **Mg** **12** **24.305**

Iron, oxygen, silicon, and magnesium are the most abundant elements of Earth, followed by sulfur, nickel, calcium, and aluminum.

First produced in 1808 by Humphrey Davy, by electrolysis of its compounds. Name is from Magnesia, in northern Greece, whence came the ores from which it was first derived.

Abundant in seawater, from which it is commercially produced; one of the processes also uses seashells for calcium, which is needed in the reaction. Useful alloy with aluminum.

Manganese **Mn** **25** **54.9380**

Many properties (including rust) similar to iron, its neighbor. Named by its discoverer, Scheele (1774) because the ore has magnetic properties. Adds shock resistance when alloyed with steel.

Meitnerium **Mt** **109** **(266)^d**

Discovered 1982, in Darmstadt. Only three atoms were created, which decayed after 0.0034 second, enough to identify their structure.

Extremely short-lived. Created using particle accelerators. Named for Lise Meitner, a co-worker of Otto Hahn, who “finally understood how atoms could be split wide open” (book blurb). As of 6/01, no element heavier than Hs (108) has had its chemical properties analyzed.

Known isotopes: . Most stable: .

Mendelevium Md 101 (258)^c

Discovered 1955 by Ghiorso et al. (Me-256). Only trace amounts made.

Known isotopes: 13. Most stable: Me-258.

Mercury Hg 80 200.59

Chemical symbol stands for hydrargum, “liquid silver”. Melts at -39°C (-38.2°F). The unusually low melting point has no explanation under current theory. Found chiefly as mercury sulfide, in cinnabar (a.k.a. vermilion), from which it is recovered by heating and then condensing the mercury vapor. (Looks like this is how it was recovered anciently.) Samples found in Egypt date from 8500.

Dissolves other metals, including gold and silver, “to form alloys known as amalgams.”

Molybdenum Mo 42 95.94

First isolated and identified by Scheele in 1778. Named from the Greek *molybdos* = lead. (Its ore, already known as molybdenite, was first thought be a lead ore.)

Molybdenum steel is especially useful in engines and other high-temperature applications. A radioactive isotope, ^{99}Mo , next to Tc on the periodic table, decays into technetium-99, which has medical applications.

Moscovium Mc 115

Synthesis first reported (with that of 113) Jan. '04, by the Joint Institute for Nuclear Research, Dubna & Livermore, led by Yuri Oganessian. (*Physical Review C*, *NYT* 2/1/04, *SN* 2/7/04.) (*SN* 7/9/16.14.) Name accepted in 2016. 113 & 115 have unusually long lives for elements in this range (up to 1.2 seconds, per *SN*), reinforcing hopes for an “island of stability” at higher atomic weights.

Only about 30 atoms produced as of ~2012.

Known isotopes: several, all extremely unstable. Most stable: Mc-289, h/1 220 milliseconds. Mc-287, Mc-288.

Neodymium Nd 60 144.24

See Praeseodymium for discovery and naming. Has a weakly radioactive isotope, Nd-144. Magnetic, used in powerful—and inexpensive—magnets. This makes them useful in generating electricity from rotary motion, as in wind turbines.

Neon Ne 10 20.179

Discovered along with other noble gases by William Ramsay in 1898, following his discovery of argon. First used for lighting in 1910. (Other noble gases are also used in lighting.) It makes up about 0.002% of the atmosphere, which it makes it the fifth most common atmospheric element. It is produced commercially by liquefying air and then letting the more volatile atmospheric gases escape as the air warms. (Other atmospheric gases are isolated in the same way.)

Neptunium Np 93 237.0482^b

Named for Neptune, the planet after Uranus. A by-product of nuclear reactors. Discovered in the USA in 1940 using a cyclotron. It was the first of the synthetic transuranic elements to be found. Actually occurs in trace amounts in nature as a decay product. 18 known isotopes, the most important being Np-237.

Nickel Ni 28 58.69

Iron, oxygen, silicon, and magnesium are the most abundant elements of Earth, followed by sulfur, nickel, calcium, and aluminum. Discovered in the 1700s.

Magnetic. Stainless steel typically contains 18% chromium and 8% nickel. Alloyed with chromium for electric heating elements (nichrome), used for its high melting point and high electrical resistance.

From the German *Nickel*, a troublesome earth being (alibi, Satan: Old Nick?), because it made difficult the refining of copper from ore (or on another account, because it is itself difficult to smelt). (Cf. cobalt.) U.S. nickels are over 75% copper, and not magnetic; Canadian nickels have more nickel and are magnetic.

Nihonium Nh 113

Synthesis first reported (with that of 115) Jan. '04, by the Joint Institute for Nuclear Research, Dubna & Livermore, led by Yuri Oganessian. (*Physical Review C*, *NYT* 2/1/04, *SN* 2/7/04.) (*SN* 7/9/16.14.) Name accepted in 2016, honoring Japan. (A Japanese team had observed an atom of it a few months after the first discovery.) 113 & 115 have unusually long lives for elements in this range (up to 1.2 seconds, per *SN*), reinforcing hopes for an "island of stability" at higher atomic weights.

Known isotopes: "a number". Most stable: Nh-286, h/l 28.3 sec.

Niobium Nb 41 92.9064

Niobium and tantalum, one above the other on the periodic table, have very similar chemical properties and are always found together.

Discovered in 1801. Originally, and still occasionally, called columbium, because it was first found in a mineral (from the Connecticut valley) called columbite.

"Titanium and niobium, and even aluminum, can be toned to a whole rainbow of colors by deft application of heat, electricity, and chemical reagents." Toned Ti, Nb, and Al are used in knife handles. (Levine 5.)

Nitrogen N 7 [14.00643; 14.00728] (old: 14.0067)

Nitrogen is the most abundant element in the universe after hydrogen, helium, carbon, and oxygen.

Discovered in the 1700s. Named as the source of niter.

Solid nitrogen has been created in the laboratory, using a diamond anvil and super-low temperatures. (*SN* 159.349, 6/2/01.)

Diatomic nitrogen makes up almost 80% of the atmosphere. Plants and animals cannot use diatomic nitrogen directly. Nitrogen-fixing bacteria in the roots of some plants, and in the oceans, can split the diatomic nitrogen, making it available for plants.

Nitrogen is used commercially as a food preservative, pumped into packaging to replace air (and specifically oxygen). Argon now beginning to be used for this purpose. *SN* 9/8/01 160.159.

Nobelium No 102 (259)^c

First unambiguous discovery by Ghiorso et al., 1958 (No-254). Ghiorso accepted the name proposed by the Swedish group that first claimed the discovery. Named after Alfred Nobel, discoverer of dynamite and institutor of the prize. Exists only in trace amounts, too small for chemical and physical properties to be analyzed.

Known isotopes: 11. Most stable: No-259.

Oganesson Og 118 (293)^d

Name accepted in 2016, honoring physicist Yuri Oganessian. In 1999, researchers at Berkeley reported creation of three atoms of element 118 (*SN* 6/12/99, p. 372). (*SN* 7/9/16.14.) The claim was retracted in 2001 (*SN* 160.68, 8/4/01); ("a scientist at Livermore was found to have fabricated evidence" (*NYT* 2/1/04, reprinted *Mpls S-T* 2/1/04). The discovery had excited hopes of reaching an "island of stability" among elements heavier than any previously created. Synthesis (of three atoms) was achieved in 2002 by a Russian-American collaboration led by Yuri Oganessian. Experimental validation was made in 2005. As with the synthesis of many of the heaviest elements, a target made of a chosen isotope was bombarded with isotopes of an ion of another chosen element for a very long time (in this case 96 days), as needed to realize the infinitesimal chance of a fusion of the two nuclei; the atoms were identified by "their unique decay patterns".

Extremely unstable.

Known isotopes: . Most stable: . First synthesized: Og-294

Osmium **Os** **76** **190.2**

Discovered 1803. Named from the Greek *osme* = smell: it oxidizes into a stinking, toxic gas. Like other metals near it in the period, has an extremely high melting point. Refined from ores along with nickel and platinum. Alloyed with other metals to add hardness, as in fountain-pen nibs.

Oxygen **O** **8** **[15.99903; 15.99977] (old: 15.9994)**

Oxygen is the most abundant element in the universe after hydrogen, helium, and carbon. Iron, oxygen, silicon, and magnesium are the most abundant elements of Earth, followed by sulfur, nickel, calcium, and aluminum.

Discovered and recognized as an element by Priestley in 1774. (Others had produced it earlier, and Atkins notes a Swedish chemist, Karl Scheele, who discovered it two years before Priestley but lost his priority due to publication delays. Atkins seems to imply that Scheele had recognized it as an element.) Named by Lavoisier from *oxy*, acid, in the belief that it was a universal constituent of acids.

Oxygen is the second most electronegative element (after fluorine which is 500x less abundant, chlorine is third; francium is least electronegative). This is why oxygen is the most effective medium for energy transfer, and thus the most effective basis for life.

Palladium **Pd** **46** **106.42**

Named for the asteroid Pallas, discovered at about the same time as the element's discovery in 1803. (Cf. cerium.) V.q. Platinum. A valuable catalyst in the making of medical compounds.

Phosphorus **P** **15** **30.973** **76**

Discovered 1669 by alchemist Henning Brand, in the residue of evaporated urine.

Platinum **Pt** **78** **195.08**

Named from *platina*, dim. of Spanish *plata* = silver. A nugget was found by Antonio de Ulloa in Colombia, and its properties were then recognized; Jaffe gives the date 1735 for one or both of these events. Platinum, palladium, ruthenium, and iridium are important as industrial catalysts; their rarity and expense is an issue. (On this, and catalysis generally, *SN* 3/4/17.21.) A critical industrial metal. World production is about 80 tons a year, mostly from South Africa, also in the Urals. Usually found pure, since it does not react with atmospheric oxygen, but mixed with other metals.

Plutonium **Pu** **94** **(244)^c**

Discovered in 1941 by Glenn Seaborg. Named for the planet Pluto, the planet beyond Uranus and Neptune. Pu is (often or always?) a by-product of nuclear reactors, being extracted from the spent fuel. Causes fission chain reactions like uranium, releasing huge amounts of energy. Produced in huge quantities in "breeder reactors" designed for the purpose, and also in other reactors, thus favored for nuclear weapons.

15 known isotopes; most important is Pu-239, h/l 24,000 years. Pu-239 does not fission, but produces energy, and is used as a power source in spacecraft and in pacemakers.

Polonium **Po** **84** **(209)^c**

Discovered, along with (a bit later) radium, in 1898 by the Curies. Named for Marie's native country. Radioactive; has 27 known isotopes, all radioactive, some very highly. P-210 is amazingly toxic, ~250,000 times as toxic as cyanide.

Potassium K 19 39.0983

"A silvery, reactive metal." So reactive, in fact, that it is dangerous to handle. First produced in 1807 by Humphry Davy, by electrolysis of caustic potash (potassium hydroxide), and named for its source material. The chemical symbol is from the Latin name *Kalium*.

Like other alkali metals, reacts violently with air to produce hydrogen, which may catch fire. The isotope P-40 is radioactive, and makes up about 0.012% of natural potassium, contributing significantly to natural radiation dosage in life forms.

Praseodymium Pr 59 140.9077

Discovered in 1885, along with neodymium. Named for *praeseos*, from the green color of its oxide, and *didymos*, twin, because it was twinned with neodymium as one of two salts derived from the mineral didymium.

Alloyed with magnesium for auto and aircraft parts. 5% Pr, along with 18% Nd, is in Mischmetal, used in steel alloys and in cigarette-lighter flints: Pr gives off sparks when scratched.

Promethium Pm 61 (145)^c

Named for Prometheus. Discovered in 1947 at Oak Ridge National Laboratory, after the predicted element had long been sought. The only rare earth known only as a synthetic element; it has been identified in the spectra of certain stars in the Andromeda galaxy.

28 isotopes synthesized so far, all radioactive, including Pm-145, -147. Pm-147 emits electrons, and is used in nuclear batteries for spacecraft and missiles.

Protactinium Pa 91 231.0359^b

Discovered 1913. (Jaffe: existence established 1917, first isolated 1934.) Named from proto-actinium, because the decay product of protactinium is actinium. Stwertka: "One of the scarcest and most expensive of the naturally occurring elements." A decay product of uranium. "Only a few hundred grams of protactinium are available for study. This meager amount was largely produced in England some 30 years ago, ... it was extracted from 60 tons of ore at a cost of half a million dollars." Extremely toxic anyway. 22 known isotopes; the longest lived is Pa-231.

Radium Ra 88 226.0254^b

Predicted, discovered in 1898, and then experimented on by Marie Curie, in collaboration with her husband Pierre. (V. Uranium.) Not actually *isolated* until 1910, by Marie after Pierre's death. Named from *L. radius*, ray. A decay product of uranium. 30 known isotopes. The most common, Ra-226, has a half-life of 1630 years.

Radium was fantastically scarce in the early days. In 1921, there were 150 grams in the world; that year discovery of rich ores in the Belgian Congo cut the price in half. Today, world production is about 5 pounds annually (Stwertka).

Radon Rn 86 (222)^c

Isolated by Ramsay in 1898, who named it *niton* (from *nitens*). 20 known isotopes, all radioactive. The longest lived has a half-life of 3.8 days. It occurs naturally as a product of radioactive decay. Decays into a radioactive isotope of lead, which is much more stable and accumulates in the lungs. This is apparently the major health hazard of radon; it is estimated to cause 10% of the lung cancer in the U.S.

Rhenium Re 75 186.207

Discovered in 1925, by a team that had predicted it from its periodic properties. Named from *Rhenus*, the Rhine. One of the rarest elements. Used chiefly in alloying with metals.

Rhodium Rh 45 102.9055

Named from the Greek *rhodon* = rose, from the color of many of its salts. Discovered in 1803. Rare, more costly than gold or platinum, but has industrial applications. Used in catalytic converters.

Roentgenium Rg 111 (272)^d

W: "It is an extremely radioactive synthetic element (an element that can be created in a laboratory but is not found in nature); the most stable known isotope, roentgenium-282, has a half-life of 2.1 minutes. Roentgenium was first created in 1994 by the GSI Helmholtz Centre for Heavy Ion Research near Darmstadt, Germany."

Known isotopes: several. Most stable: roentgenium-282, has a half-life of 2.1 minutes. Also Rg-281, h/l 23 seconds; Rg-272, h/l 1.5 milliseconds.

As of 6/01, no element heavier than Hs (108) has had its chemical properties analyzed.

Rubidium Rb 37 85.4678

Named from the Latin *rubidus*, not from the color of the element, but from that of the flame when its compounds are burned. Bursts into flame when exposed to air or water. Melts at 39°C, ~100°F.

Discovered in 1861 by Bunsen and Kirchoff.

Ruthenium Ru 44 101.07

Named from *Ruthenia*, Russia. V.q. Platinum. Used as a catalyst in industrial chemistry. Alloys are used in fountain pen points.

Rutherfordium Rf 104 (261)^d

First claim of discovery made 1964, by Dubna; the name Kurchatovium was proposed, but the claim was doubted. Clear discovery made in 1969 by Ghiorso: Rf-257 (h/l 4–5 seconds).

Extremely short-lived. Created using particle accelerators. It was also proposed that the name rutherfordium be given to element 106. Little is known of its physical or chemical properties. 104, 105; cf. 106 Sg: Properties do not seem consistent with its place on the PT.

Known isotopes: 6. Most stable: Rf-261, h/l 62 sec.

Samarium Sm 62 150.36

Discovered 1879, in a mineral called samarskite.

Has radioactive isotopes, including Sm-153.

Scandium Sc 21 44.9559

Its existence and properties had been predicted (as eka-boron) by Mendeleev. Known from 1876 ("isolated" by Nilson, says Jaffe 152; 1879 is the date another source gives for its discovery), but isolated only in 1936. Named after Scandinavia.

Seaborgium Sg 106 (263)^d

Discovery and naming disputed. Seaborg was on the team whose claim was accepted in 1994. First claim made by Dubna, 1974, but results not duplicated. Another announcement at about the same time at Berkeley (Sg-263, h/l 0.9 second); this result not duplicated until 1993. The controversy over the naming also put in question the naming of 104–108; it was resolved in 1997.

A chemical analysis was made in 1997, on a mass of only 7 atoms. Properties seem consistent with its place on the PT.

Known isotopes: 4. Most stable: Sg-263.

Extremely short-lived. Created using particle accelerators. Named for Glenn Seaborg. The name rutherfordium (finally given to element 104) was also proposed for element 106.

Selenium **Se** **34** **78.96**

Discovered by Berzelius, 1817. Named for the Moon, from the element's silvery appearance. Obtained as a by-product of copper refining and sulfuric acid production.

A poor conductor of electricity, becoming a good one when exposed to light. Thus used in photocopiers and light sensors.

Silicon **Si** **14** **[28.084; 28.086] (old: 28.0855)**

Iron, oxygen, silicon, and magnesium are the most abundant elements of Earth, followed by sulfur, nickel, calcium, and aluminum. L. *silicium* seen, early period.

Silicon dioxide, a.k.a. silica, is the main ingredient in glass. It is the material of which sponge skeletons are made; grasses and some other plants deposit silica in their stems, "presumably as a defence against grazers". (SN 160.78, 8/4/01.)

Silver **Ag** **47** **107.8682**

The best metallic conductor of electricity; used in high-end electronics. Highly ductile and malleable. Usually alloyed with copper for hardness; sterling silver, used in tableware, is 7% copper, 93% silver. Jewelry has more like 2% copper. Dental amalgam is a mixture of silver and mercury. "Silver compounds are very sensitive to light." Has antibacterial properties. Many new uses being found for silver nanoparticles, which often behave differently than silver in mass. (Same for gold.)

Sodium **Na** **11** **22.989** **77**

First produced in 1807 by Humphrey Davy, by electrolysis of caustic soda (sodium hydroxide, a.k.a. lye), and named for its source material. The chemical symbol is from the Latin *natrium*. Highly reactive, like all alkali metals; not found free; pure sodium must be stored in liquid to prevent contact with air. Melts at 98° C.

The name comes from E *soda*, which derived from L *sodanum*, a headache remedy per Stwertka.

Strontium **Sr** **38** **87.62**

First produced in 1808 by Humphrey Davy, by electrolysis of its compounds. Named from Strontian, in Scotland, where it was first identified in 1789.

The isotopes ^{87}Sr and ^{90}Sr are radioactive.

Sulfur **S** **16** **[32.059; 32.076] (old: 32.06)**

Iron, oxygen, silicon, and magnesium are the most abundant elements of Earth, followed by sulfur, nickel, calcium, and aluminum.

The name is originally derived from Sanskrit *sulvere*, per Atkins, who gives no meaning.

Sicily was long the primary source for sulfur, producing as much as 95% or the world's supply. Exploitation of deposits in Texas and Louisiana took more of the market later.

Sulfur melts at 110–120° C.

Tantalum **Ta** **73** **180.9479**

Discovered 1802 by Anders Gustav Ekeberg; another element isolated from minerals found near Ytterby. Named for Tantalus, father of Niobe. Niobium and tantalum, one above the other on the periodic table, have very similar chemical properties and are always found together. Pure tantalum was not isolated from niobium until 1903, and many chemists for about fifty years thought that Ekeberg was mistaken in distinguishing tantalum as a separate

element. "Extremely hard and heavy." Ductile. Extremely high melting point; like gold and platinum in ability to resist chemical attack "at temperatures below 150° C". Less costly than platinum. Alloyed with other metals. A tantalum carbide created at Los Alamos "is supposed to be the hardest material ever made."

Technetium Tc 43 (98)

Tc and all its isotopes (19 known) are radioactive, and known on Earth as a by-product of uranium decay in the nuclear industry or as the product of a radioactive isotope of molybdenum, ⁹⁹Mo, which decays into technetium-99, which has medical applications. There is also an unstable variety of technetium-99, designated as technetium-99m.

It has been detected in stars. Its existence was predicted by Mendeleev; it was discovered in 1937 by Emilio Segrè and Carlo Perrier. Named from the Greek *technikos* = artificial, it being the first element to be produced artificially. It does not occur naturally on Earth because of its short half-life of 200,000 years: all of the Tc originally formed with Earth has decayed (Pagels, *PS*, p. 60–61). The Tc observed in stars is recently created.

Tellurium Te 52 127.60

A metalloid. "One of the few elements that combines with gold." "Often recovered as a by-product in the refining of gold" and copper. Discovered in 1787; named for Tellus. Chiefly used as an alloy with copper and steel, etc. to enhance machinability.

Tennessee Ts 117

Discovered 2010.

Known isotopes: . Most stable: . First made: Ts-293, h/l 21ms, and Ts 294, h/l 45 ms.

(*SN* 7/9/16.14). Name accepted in 2016, honoring the state of Tennessee.

Terbium Tb 65 158.9254

Named (like three other elements) from Ytterby, a small town in Sweden, where a variety of minerals have been found, among them yttria and erbia. Discovered in 1843. Among other uses, it is a "critical component" of CFL lightbulbs.

Thallium Tl 81 [204.382; 204.385] (old: 204.37)

Discovered 1861, by William Crookes. Named from the Greek *thallos* = green shoot, not from the color of the element, but from that of the flame when it is burned. Resembles Pb (82). Scarce; generally a by-product of lead and zinc production. Reactive. Toxic. Few commercial applications. (Now banned in U.S. for use as rat poison.)

Thorium Th 90 232.0381^a

Discovered 1828. Named for the god Thor. Thorium-232, the isotope that occurs naturally, is only weakly radioactive, with a half-life of 14 billion years. (But cf. uranium, also weakly radioactive, but with many highly reactive decay products. Is Th similar in this?) Can still fog photographic film in a few hours. Some commercial applications, in alloys with magnesium for high-temperature use, and in the mantles for some portable gas lamps. 25 known isotopes, some with infinitesimal half-lives.

Thulium Tm 69 168.9342

Extremely scarce. Discovered 1879, isolated from erbia.

Tin **Sn** **50** **118.69**

Melts at 450°F. Has three allotropes, depending on temperature; at extremely low natural temperatures, as in a Russian winter, the metallic allotrope changes to a powdery allotrope.

Very malleable, thus once widely used in foil form. Tin is safe for food use, and resistant to corrosion. Once plated over steel for tin cans; “the tin protected the steel from attack by food acids.”

Tin is alloyed with copper to form bronze, with lead to form solder. Pewter is an alloy of 85% tin with copper, bismuth, and antimony.

Stwertka: “Relatively rare, ranking 50th or so in the abundance of elements in the Earth’s crust.” It is relatively expensive, and is thus more often used plated than in structural form. Easily recovered from ore, and apparently often abundant where found.

The chemical symbol comes from the Latin stannum. (V. *LS* s.v., and Tucker s.v. stagnum.)

Titanium **Ti** **22** **47.88**

Named after the Titans, for their strength.

Light and strong; its high melting point is also an advantage in such applications as rocketry. Extraordinary corrosion resistance (nonetheless, ruthenium is sometimes added to improve corrosion resistance); virtually immune to metal fatigue. It has been used for knives and tools. Expensive to produce by the chemical processes used for it, but a promising new electrolytical method was reported in 2000, which may be why it seems to have become more common. It is also difficult to machine, which restricts its commercial application. Stwertka: “10,000 pounds of titanium and its compounds are used in each engine of a Boeing 747 jet.”

“Titanium and niobium, and even aluminum, can be toned to a whole rainbow of colors by deft application of heat, electricity, and chemical reagents.” Toned Ti, Nb, and Al are used in knife handles. (Levine 5.)

Tungsten **W** **74** **183.85**

Also Wolfram. Discovered 1781 (alternately, 1783). The element may have been known before that time, by the name “wolfram”. “Tungsten” is from the Swedish for “heavy stone”. Isolated from a mineral called wolframite. Still widely referred to, esp. in Germany, as wolfram.

Highest melting point of any metal: 3410° C. This is why it is used in lightbulb filaments. (The bulbs are filled with inert gases to prevent the filament from overheating.) Th filaments vaporize over time, leaving a dark deposit on the inside of the bulb.

Also alloyed with steel for edge-holding at high temperatures. Tungsten carbide is not only extremely hard, but chemically inert even at high temperatures.

Upsidaisium **Up** **?** **(negative)**

A strategic metal with anti-gravity properties, found in a mine at Mt. Flatten, and known to the public only as the subject of a 1960–61 story arc in the *Rocky and His Friends* cartoon series. Mt. Flatten was flown to Washington D.C. by Rocket J. Squirrel, and has since been kept completely under wraps by the U.S. government.

Uranium **U** **92** **238.0289**

The heaviest naturally occurring element: elements up to U can be created in the collapse of very massive stars. (Cf. Fe.) Discovered in 1789, isolated as an element circa 1842. Named for the planet Uranus. Stwertka: “once considered scarce, it is now found in many minerals.” Weakly radioactive (h/1 6 billion years), but with many highly reactive decay products. Highly toxic over and above its radioactivity.

Jaffe 186: “Uranium salts had been known since 1789; they had been used to color glass. There was nothing very remarkable about this substance”—that is, until Becquerel, in 1896, discovered what turned out to be its radioactive properties. He soon found indications that there was another substance much more powerful than U, and asked Marie Curie to seek to isolate it—and thus Polonium, and then Radium, were discovered.

Three most important isotopes: U-238, 99% of a typical sample of uranium; half-life of 4.6 billion years. U-235, half-life 700 million years; often used to enrich nuclear fuel. U-234, half-life 25 million years.

Vanadium **V** **23** **50.9415**

“Named after the Scandinavian goddess of beauty” (Atkins), because its compounds take on a rainbow of colors. (It was, however, discovered by a Mexican mineralogist, in 1801.)

Xenon **Xe** **54** **131.29**

Discovered along with other noble gases by William Ramsay in 1898, following his discovery of argon. Used in lighting: “under high pressure, emits a white, sunlike light when an electric current is applied to it.”

Ytterbium **Yb** **70** **173.04**

The first of the rare earth elements to be discovered, in 1878. Named (like three other elements) from Ytterby, a small town in Sweden, where a variety of minerals have been found, among them yttria and erbia.

Yttrium **Y** **39** **88.9059**

Named (like ytterbium, erbium, and terbium) from Ytterby, a small town in Sweden, where a variety of minerals have been found. First identified in 1799 by Johan Gadolin.

Zinc **Zn** **30** **65.38**

Discovered 1746. Jaffe 154 says it was first mentioned by Paracelsus.

Melts at 419°C (787°F). Alloyed with Cu to form brass. Zinc is the corrosion-resistant coating on galvanized iron; the presence of zinc prevents corrosion even if the zinc coating is scratched, since zinc oxidizes more readily.

[[May be toxic, or give off toxic fumes in some processes.]] It is, however, a common ingredient in sunscreens, not to mention pigments.

Zirconium **Zr** **40** **91.22**

A strong durable metal, with aerospace applications. Difficult to isolate from hafnium, just below it on the periodic table. Discovered in 1787.

Zircon, the mineral and semiprecious gem, was known anciently, and mentioned in the Bible; the name comes from Arabic *zargun*.

GROUPS OF ELEMENTS

METALS

Astronomers use the term “metal” for all elements heavier than helium—that is, for all elements that are (only?) created by nuclear fusion within stars. The category of “high-metal stars” is significant for the chemistry of planet formation.

ALKALI METALS (1)

All highly reactive, so never found free in nature. All soft and silvery in pure state.

ALKALINE EARTH METALS (2)

All highly reactive, so never found free in nature.

TRANSITION METALS (GROUPS 3–12, D-BLOCK)

In the transition elements, “as the number of protons in the nucleus increases across each period, electrons are added to an incompletely filled inner shell rather than to the outer, valence, shell. Consequently, the number of valence electrons is virtually the same for all these elements.” Thus, they tend to resemble each other in their chemical behavior. “All of them, for example, are fairly unreactive metals, and many of their compounds are colored.” Cf. F-block.

COINAGE METALS (11)

F-BLOCK

[p/u from periodic table] Note that the elements of the d-block, which contains the f-block, are also of similar valence and chemical properties, though not to the extent of the f-block.

LANTHANOID SERIES (“RARE EARTHS”)

Stwertka, s.v. lanthanum, actinium: “This series, also called the lanthanide series, consists of lanthanum and the next 14 elements that follow it across the periodic table. The last member of the series is lutetium (atomic number 71). All of the elements that make up this series [and the Actinoid Series] are characterized by having their added electrons, the number of which increases with the atomic number of each element in the series” in “an inner orbital shell, the second such shell from the outer valence shell.”

Since the outermost electrons have the greatest influence on the properties of the elements, it should not be surprising that the variations in the properties of the rare earth elements are not as dramatic as the variations observed as one moves across the group-A elements, to take but one example. Many of the properties of lanthanum are, for instance, more or less typical of all the elements in the rare earth series. In their pure forms, they are typically soft, ductile, silvery metals.

Because of their chemical similarity, it is quite common to find most of the rare earth elements, usually in the form of their oxide compounds, mixed together in the minerals that contain these elements. It is this mixing that has led to the name “rare.” The abundance of the rare earths in the Earth’s crust is actually comparable to that of such common metals as zinc, tin, and lead. But unlike these metals, a rare earth element is not concentrated in a geological vein or outcropping that can be easily mined.

They all (except, as yet, lutetium) have industrial or medical uses, often high-tech. Many are used for coloring light in TV and computer screens (CRTs or LEDs?), or for medical lasers, or as alloys with other metals.

China produces 97% of the world supply of rare earths, from mines in Inner Mongolia. They are also found in certain sands in various parts of the world, an in ores in a few other places, but it is usually not economical to obtain them from these sources.

EB11, s.v. rare earths, has detail on the history of their discovery and extraction, and their chemical groupings as then understood.

ACTINOID SERIES (“Second Inner Transition Series”)

Electronic and chemical characteristics similar to Lanthanoid series; likewise have “similar chemical and physical properties.” Apparently found in the same minerals and sands.

PNICTOGENS (15)

No one ever tells you what pnictogens are. Are they related to fionds?

W: “The term pnictogen (or pnigogen) is derived from the Ancient Greek word πνίγειν (pnígein) meaning ‘to choke’, referring to the choking or stifling property of nitrogen gas.”

CHALCOGENS (16)

HALOGENS (17)

“Salt formers.”

NOBLE GASES (18)

This column was added to the periodic table after the discovery of argon in 1894.

All are monatomic. All are used to generate colored light when juiced with electricity.

The first compound of a noble gas was made in 1962: a solid consisting of xenon, platinum and fluorine. Other xenon compounds with fluorine were later made. Linus Pauling predicted a compound of noble gases, KrF_4 , in 1933, using quantum mechanics. It was produced in 1966. It is still the only known compound of krypton. In 2000, a Finnish team succeeded in producing a compound of argon with fluorine and hydrogen, HArF ; it can subsist only at extremely low temperatures.

OTHER CATEGORIES OF ELEMENTS

METALLOIDS

W: The six commonly recognized metalloids are boron, silicon, germanium, arsenic, antimony, and tellurium. Five elements are less frequently so classified: carbon, aluminium, selenium, polonium, and astatine. On a standard periodic table, all eleven are in a diagonal area in the p-block extending from boron at the upper left to astatine at lower right, along the dividing line between metals and nonmetals shown on some periodic tables.

Typical metalloids have a metallic appearance, but they are brittle and only fair conductors of electricity. Chemically, they behave mostly as nonmetals. They can form alloys with metals. Most of their other physical and chemical properties are intermediate in nature.

SIDEROPHILE ELEMENTS

Elements 44–46, 74–79. Strongly tend to combine with iron, thus 98% of them drawn with it to interior of Earth, therefore rare on surface. V. int. article, SN 8/6/16.22.

“ISLAND OF STABILITY”

It is confidently predicted that elements will be found that are [relatively stable]. This would validate some important physics. It could also lead to elements with interesting and useful properties.

Stability is predicted of nuclei with 184 neutrons and either (114 or 126 protons or 120 and 126 protons: Stwertka gives both pairs).

The prediction is based on a theory that “nuclei contain spherical quantum shells similar to those occupied by the electrons of an atom. When neutrons and protons filled these shells, the resulting nucleus was predicted to be more stable.”

3/2/19.16ff. “Prospecting the Periodic Table: weird new elements could reveal nature’s extremes”, by Emily Conover. ***** On the theory and importance to chemical knowledge of elements in the “island of stability”. Lucid explanation of the heavy extreme (and limits) of the periodic table, with much of importance that is new to you. XX filed in chemistry notebook.
To digest here and elsewhere. Of note: there is an upper limit to the atomic weight of possible elements.

MISCELLANEOUS NOTES

CREATION OF ELEMENTS

Science News, Feb. 18 2017, p. 22

Once a star’s core runs out of hydrogen, it fuses helium into carbon, oxygen and nitrogen. For stars like the sun, that’s about as far as they get. But if the star is more than about eight times as massive as the sun, it can keep going, forging heavier elements. All that weight on the core keeps the pressure and temperature extremely high. The star forges progressively heavier elements until iron is created. But iron is not a stellar fuel. Fusing it with other atoms doesn’t release energy; it saps energy from its surroundings.

Without an energy source to fight against gravity, the bulk of the star comes crashing down on its core. The core collapses on itself until it becomes a ball of neutrons, which can survive as a neutron star—a hot orb about the size of a city with a density greater than that of an atomic nucleus. If enough gas from the dying star rains down on the core, the neutron star loses its own battle with gravity and forms a black hole. But before that happens, the initial onrush of gas from the rest of the star hits the core and bounces, sending a shock wave back toward the surface, tearing apart the star. In the ensuing explosion, elements heavier than iron are forged; more than half of the periodic table may originate in a supernova.

Newly formed elements aren't the only things a supernova spits out. Theorists had predicted that neutrinos, nearly massless subatomic particles that barely interact with matter, should be released during the core collapse, and in no small quantity. Despite their ghostly nature, neutrinos are suspected to be the main driving force behind the supernova, injecting energy into the developing shock wave and accounting for about 99 percent of the energy released in the explosion. And because they pass through the bulk of the star unimpeded, neutrinos can get a head start out of the star, arriving at Earth before the blast of light.

p. 27: some trans-ferric elements are produced by the "r-process", which may require the merging of neutron stars.

ATOMIC AND NUCLEAR STRUCTURE

The *atomic number* (Z) is the number of protons in the nucleus of an element. The *atomic mass* includes the mass of the neutrons. Neutrons have nearly the same mass as protons. (That of the electrons is negligible.)

Isotopes are variants of an element with differing numbers of neutrons—thus the isotopes have different atomic masses. "Isotope" refers to the fact that all isotopes of a given element occupy the same place on the periodic table. Apparently all the variations, including the canonical form, are referred to as "isotopes". The canonical ones are, I believe, stable ones. Most elements (including Au, Fl, As) have a single, predominant stable form, though some elements have more than one stable isotope. Elements may have many isotopes. (26 are known for actinium.) Proportions of isotopes of a given element may vary with the natural origin.

Isotopes are designated by ideal, integral atomic mass numbers, e.g. carbon-12, or ^{12}C . (In full notation, the atomic mass precedes the element as a superscript, the atomic number below it as a subscript.)

Considered from the point of view of nuclear rather than chemical properties, isotopes are referred to as "nuclides", and the exact number of each nucleon is important. Remarkably, whether the numbers are even or odd has implications for the stability of the nuclide. (Shades of Pythagoras!) The most stable (148 of them, 58% of stable nuclides) have even numbers of both protons and neutrons. "Half of these even-numbered elements have six or more stable isotopes." Most of the rest have an even number of one nucleon, and an odd number of the other. 53 have even protons, odd neutrons. 48 have odd protons, even neutrons. Least common are odd-odd nuclei—only 5 stable ones are known. W: "As a result, each of the 41 even-numbered elements from 2 to 82 has at least one stable isotope, and most of these elements have several primordial isotopes."

The ratio of neutrons to protons increases with atomic number, since larger numbers of protons, having identical charges and therefore repelling each other, will not hold together unless higher ratios of neutrons are present.

Atomic mass (weight) figures historically given for elements (except unstable elements, which "have no standard atomic weight") are actually averages of a mass containing varying isotopes, since a given sample will contain more than one isotope of an element. Thus the numbers are not integral.

The unit of atomic mass is the average mass of a nucleon (proton or neutron), defined as one twelfth of the mass of a standard, at rest, uninfluenced, carefree carbon atom (which has six protons and six neutrons). This is more or less 1.66 yoctogram (give or take a smidge).

Standards for the unit have varied, being last fixed in 1961. Increasingly precise measurements and knowledge about the abundance of various isotopes in nature have complicated the picture of atomic weight.

In an effort by IUPAC begun in 2011, the masses are being re-examined and calculated more precisely. Some elements (beginning with H, Li, B, C, N, O, Si, S, Cl, Tl) will have their atomic mass expressed as a range (with perhaps a pie chart showing distribution in nature), though for most there is a single predominant, energetically stable form (Au, Fl, As, inter alia, exist in only one stable form), and unstable elements "have no standard atomic weight". (SN 1/29/11.5.)

The new data will be expressed as ranges, bounded by square brackets, the extremes separated by a semicolon+space. New weights for ten elements have been determined as of late 2010:

H	[1.00784; 1.00811]
Li	[6.938; 6.997]
B	[10.806; 10.821]
C	[12.0096; 12.0116]
N	[14.00643; 14.00728]
O	[15.99903; 15.99977]
Si	[28.084; 28.086]
S	[32.059; 32.076]
Cl	[35.446; 35.457]
Tl	[204.382; 204.385] (thallium)

The *core* of an atom is the nucleus plus the completed inner electron shells. The *core charge* is the atomic number minus the number of electrons in the completed inner shells—i.e., it is the number of electrons in the valence shell (presuming the atom is not an ion). "The outer shell electrons experience the charge of the core rather than the full charge of the nucleus." (Gill.)

ELECTRONIC STRUCTURE AND PERIODICITY

Groups 1,2, 13–18 are called “representative elements”; 3–12 are the “transition elements”. All elements in a group have the same number of electrons in their valence shells.

The farther an electron is from the nucleus, the less tightly it is bound to the atom.

The ground state, or lowest energy state, of an element, is also its most common electronic structure, which can be used to characterize that element. Electronic structure is described by terms of the form Xs^y (e.g., $1s^2$), where X is the energy level of the orbital, $s/p/d/f$ (Senatus Populusque Demetrii Filiorum) are the types of orbital, and y is the number of electrons in orbitals of that type at that energy level. The orbitals are the different types of standing wave with which the electron can be identified (under wave/particle duality); it is in the nature of standing waves that they can have only integral [zero or positive] numbers of divisions (Gill., 348ff).

Each type of orbital has its characteristic shape (for more on the shapes and their explanations, see Gill., 348ff), and each can exist at a range of energy levels (and corresponding diameters), that is, in a range of shells. The lowest-energy s -orbital (that of the first shell) is called a $1s$ -orbital, the next highest (that of the second shell) a $2s$ -orbital, and so on. An s -orbital is spherical. In the $1s$ -orbital, the point of greatest density is in the nucleus; the s -orbitals of higher shells have increasing numbers of spherical nodes (plotted as subspheres of the orbital) of infinitesimally low density.

The quantum theory of electron shells and subshells (= orbitals?) was developed by Niels Bohr.

Orbitals represent different energy levels, and may be referred to as “energy levels”. With somewhat more energy than is needed to form a $2s$ -orbital, an electron can form a $2p$ -orbital. A p -orbital has two lobes, with 0 density at the nucleus and in the nodal plane that bisects the nodes at the nucleus. In each shell at which p -orbitals can form, three p -orbitals are available: one each in the x , y , and z axes. These are distinguished as p_x , p_y , and p_z -orbitals. In the third shell, an electron may occupy a $3s$ -orbital, a $3p$ -orbital, or a $3d$ -orbital. (In fact, the $4s$ orbital will be filled before the $3d$, since it has a slightly lower energy level.) A d -orbital has four lobes, and five d -orbitals are available at each energy level; the nodal planes represent 0-densities. In the fourth shell, an electron may occupy either a $4s$ -orbital, a $4p$ -orbital, a $4d$ -orbital, or a $4f$ -orbital. An f -orbital has six lobes, and a total of seven f -orbitals are possible in each shell; again, the nodal planes represent 0-densities. (The language in Gillespie, et al. and Atkins does not preclude further types of orbitals, but these four are apparently sufficient to explain the structure of elements known so far. The letters s , p , d , and f are derived from early spectroscopic terminology, apparently unimportant for understanding electronic structure.)

From the laws of electronic structure spring the succession and periodic order of the elements, as described by the “building up principle” first propounded by Bohr (in which the succession of elements is seen as the addition, one by one, of electrons to the electronic structure of a hydrogen atom) in conjunction with Pauli’s exclusion principle (a fundamental and underived axiom of physics), which states that no more than two electrons can occupy any one orbital, and these must have opposite spins. (On the Pauli principle, see Gill. 356; Pagels, *PS*, pp. 58, 305; *Physica* notes on fermions under Fundamental Particles—General. Such exclusion is a characteristic of fermions, which have half-integer spins.) (Electrons in a given shell have some general tendency to behave in pairs: Gill. 188ff).

From the exclusion principle it follows that, once two electrons occupy each lobe of an orbital, a third electron, when added, must occupy an orbital of the next energy level. Within the same shell, energy levels of the different types of orbitals (also called “subshells”) differ because increasing numbers of nodal planes make for decreasing attraction by the nucleus, leaving the electron with more energy. (Attraction also decreases with distance from the nucleus, due to shielding and repulsion by inner electrons.) The lowest is s , the next lowest p , then d , then f . But energy levels overlap slightly between shells, starting with shells $3/4$. Thus, for example, in the fourth period, $3d$ -orbitals are not occupied until the $4s$ -orbital is filled, and $4p$ -orbitals are occupied only after $3d$ -orbitals are filled.

The shell is not actually an expression of energy level, but of successive sequences of orbital types [and of increasing distance from the nucleus]. The sequence of energy levels starts with $1s$, $2s$, $2p$, $3s$, $3p$, $4s$, $3d$, $4p$ (Gill. 342). After this point the sequence is complicated because [energy levels for successive electrons within an orbital (or sometimes for the same ones in different electronic configurations) seem to differ, and to overlap with those of electrons in other orbitals] (MCV). The sequence as shown by the periodic table continues: $5s^a$, $4d$ (with a blip at 46 Pd), $5s^b$, $5p$, $6s$, $5d^a$, $4f$, $5d^b$, $6p$, $7s$, $6d^a$, $5f$, $6d^b$, $7p^a$, $6d^c$, $7p^b$ (MCV).

The number of elements found in a given period is thus twice the number of orbitals available in the valence shell of elements in that period. (Orbitals of the same type and energy level in different elements are not exactly identical—they vary in diameter with the mass and attraction of the nucleus. But they are the same for present purposes.)

The succession of the elements in accordance with the “building up” principle begins as follows: To the single electron in the s -orbital of H is added a second, in the same orbital (He). No further orbitals are possible at the first energy level; the first period is full. The next electron added occupies a $2s$ -orbital (Li), the next goes in the same orbital (Be). The next must go into a $2p$ -orbital (B); five more electrons can go into $2p$ -orbitals. No more orbitals are possible at the second energy level; with Ne the second period is full. In the third period, s - and p -orbitals are filled in the formation of a further eight elements. And so on. The blocks of the periodic table are named for the orbitals being filled in those sequences, that is, for the highest energy levels of the elements there (Gill. 341, 343)—but there are exceptions.

See also Transition Metals and F-BLOCK, s.v. Groups of Elements.

Valence

Valence is the number of atoms of *another* element with which one or more atoms of a given element may combine to form a molecule. This is [paradigmatically] the *maximum* number of atoms, which equals the number of electron positions empty in an element's valence shell. [E.g., the valence of F is 1.] (Exceptionally, the valence of H is also said to be one, since it normally can combine with at most one atom of any other element. For this reason, H can be counted as part of Group 7A.) However, an element may be said to have more than one valence, since one or more atoms of that element may combine with varying numbers of atoms of other elements. [This is due to the fact that atoms with the same number of valence electrons may have significantly different electronic configurations—Gill. 384f, and cf. also def. on p. 196.]

Gill. 174: The valence of Groups 1–4 is the number of electrons in the valence shell. The valence of Groups 4–8 is 8 minus the number of electrons in the valence shell. (Group 4 has a valence of 4 either way.) Gill. 365: "The number of bonds formed by an atom depends on the number of electrons in singly occupied orbitals, that is, on the number of *unpaired electrons*." (On importance of pairs, see Gill. ch. 4.)

Gill. 173: "Because the electrons of the completed inner shells of an atom are held much more strongly than the electrons in the outer shell, the inner-shell electrons are not generally involved when atoms combine." (There are regular exceptions, [due to characteristics of particular shells]—Gill. 342.)

HISTORY

ALCHEMY

N.b.: Mercury dissolves other metals, including gold and silver, "to form alloys known as amalgams."

Chaucer's "Chanoun's Yeoman's Tale" is, in the first part, an excellent general exposé of the practice, both in its self-deluding and fraudulent aspects, shown to be continuous: practitioners turn to conning others to support their own expensive efforts to actually attain the goals. The second part is a tale of how one whole-cloth fraud (not the yeoman's fled master, but another canon) beguiled a mark. It is quite incisive, reflecting Chaucer's great experience as a man of affairs, and this doubtless is a major part of its contribution to the variety of Chaucer's bouquet of tales..

Jonson's *The Alchemist* is also an excellent portrayal of the operations of an arrant fraud, and particularly valuable on the psychology of his marks.

Gillespie 393, for pictures of the sort of thing an alchemist might have been surprised with.

Also s.v. General.

GENERAL

Jaffe (highly selective notes on first part):

√14: Paracelsus: "The physician's duty is to heal the sick, not to enrich the apothecaries." "The doctors who have got themselves made doctors with money go about the town as if it were a crime for the sick to contradict them."

The sheer mass and number of the experiments of the alchemists, however mistaken their ideas, was bound to uncover things of use, and ideas that pointed beyond. However mistaken their ideas, they broke the mold of faith and harvested the fruit of experiment.

Alchemy in the Renaissance and on the fringes of the Enlightenment a far better analogue for psych than astrology. See notes in Chemistry/History section.

The ancients considered the highest spheres to be those of fire because fire had a "natural motion" upward.

28ff Phlogiston: a seminal but wrong idea. Also 52-3.

mcv: The very notion that there were irreducible elements was a radical departure from the undetermined view of matter under which transmutations were considered possible. An element was that which could not be transmuted.

41: Priestley discovered soda water, for which he received the gold medal of the Royal Society. 42: He also made hydrochloric acid (apparently for the first time; he named it muriatic acid. He also learned to make pure ammonia. He was a pioneer in the chemistry of gases. Discovered oxygen.

108: Berzelius: Invented modern chemical notation, replacing the disastrous hieroglyphics handed down from the alchemists. "If the first two letters be common to two metals, I shall use both the initial letter and the first letter they have not in common." He was speaking of their Latin names, of course.

Avogadro: distinguished atoms from molecules (the words had previously been used interchangeably): molecules were bodies consisting of two or more atoms chemically combined. Esp. important was the knowledge that the common chemical unit of many elements was a molecule of more than one atom. (In fact, the gases O H N Cl are found in molecules of two atoms.) This at last made it possible to develop a usable table of atomic weights based on observed experiments.

"Avogadro had reached his conception of pairs of atoms which combined to form molecules by postulating an audacious theory: 'Equal volumes of all gases under the same conditions of temperature and pressure, contain the same number of molecules.'" There is no record of how he arrived at this postulate, and apparently my own difficulties with understanding it (Understanding_why_it might be so and how anyone could ever think of it) are shared by better-trained minds.

129: "Berzelius himself spoke of the impassible gulf which separated organic compounds from inorganic substances. "There was thought to be a separate vital force in living matter, and that inorganic compounds could not be synthesized, but only created by living organisms. Woehler's synthesis of ureas was thus groundbreaking. He also isolated aluminum. Was a friend and colleague of Leibig. An American student of Woehler's student Jewett, Charles Hall, inspired by Jewett's discussions of Woehler's work on aluminum, was the first to develop a commercial process for its extraction, patented 1886.

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* Atkins, P[eter] W[illiam]. *Periodic Kingdom*. New York: Basic Books, 1995.

Oversimplification a problem in one area that I found (specifically, failure to mention that energy levels can overlap between shells) but well done otherwise.

Bensaude-Vincent, Bernadette, and Isabelle Stengers. *A History of Chemistry*. Deborah van Dam, tr. Harvard U.P., 1996. (Original publication: *Histoire de la chimie*, Éditions La Découverte, 1993.)

Ctl: QD11.B4413

Brief treatment of alchemy from ancient times.

Delamare, François, and Bernard Guimeau. *Colors: the Story of Dyes and Pigments*. Tr. Sophie Hawkes. Discoveries series. NY: Harry N. Abrams, 2000. (Original publication: *Matériaux de la couleur*. Gallimard, 1999.)

MM3 circ. 667.2 D

Informative. Very nice little edition, packed with good text and profuse illustrations in fine color, to Abrams' standards. The authors are scientists as well as historians of color and pigment. Worth re-reading. More historical notes could be taken on the modern chemical industry.

*Gillespie, Ronald [James], et al. *Chemistry*. 2nd ed. Needham Heights, MA: Allyn & Bacon, 1989.

Lots on basic atomic chemistry and the related physics.

**How It Works Book of the Elements*. 3rd ed. Bournemouth, UK: Image Publishing, 2015

Your essential companion to the periodic table: major chemical properties of each element, plus all the information you're curious about.

Hubbard, Henry D., and Meggers, William F. *Welch Periodic Chart of the Atoms*. Rev. ed., 1965. Skokie, Illinois: The Welch Scientific Company.

With companion book, Meggers, William F. *Key to the Welch Periodic Chart of the Atoms, 1965 edition*.

Periodic table "designed in 1924 by Henry D. Hubbard, revised frequently since 1940 by William F. Meggers. The companion book (46 pp.) is also extremely thorough, useful, and interesting, not least for the brief bio of Hubbard, a Grecian from the first class of U. of Chicago, and first Secretary of the National Bureau of Standards. Note also the two smaller-format b/w dupes of the table, repro quality.

The current successor is the Sargent-Welch periodic table, apparently still very much a classroom standard, though small-scale pics suggest there may not be as much in it as in the 1965 ed. ("Sargent-Welch, the USA's leading distributor of Science Education Supplies", for K-14. V. sargentwelch.com.)

Jaffe, Bernard. *Crucibles: The Story of Chemistry: From Ancient Alchemy to Nuclear Fission*. 4th rev. ed. NY: Dover, 1976. (1st ed. 1930.)

Readable and illuminating, highly honored. Alchemy starts with a graphic portrayal of Trevisan as a Renaissance exemplar.

Habeo. Ctl: QD21.J3

Pagels, Heinz R. *Perfect Symmetry: The Search for the Beginning of Time*. New York: Simon & Schuster, 1985.

Stwertka

*Mark Winter. *WebElements*. (<http://www.webelements.com/>)

Excellent, popular, and very highly regarded site, with information on all physical characteristics of the elements, as well as, inter alia, each element's discovery, uses, methods of isolation and commercial production, and biological and geological roles.

Zim & Shaffer, *Rocks & Minerals*, for misc. info on elements found in rocks & minerals, especially metals.

Periodical articles

Science News

[autumn 2001] "Faster, Better, Cleaner? New liquids take aim at old-fashioned chemistry." Jessica Gorman. Ionic liquids provide new ways to produce many reactions important to industry. Gen'ly interesting.

160.221, 10/6/01. "Path to new elements now looks steeper." Creation of new superheavy elements may be more difficult than previously thought.

3/2/19.16ff. "Prospecting the Periodic Table: weird new elements could reveal nature's extremes", by Emily Conover. On the theory and importance to chemical knowledge of elements in the "island of stability". Lucid explanation of the heavy extreme (and limits) of the periodic table, with much of importance that is new to you. XX filed in chemistry notebook.

AGENDA

Export Helv font kerns, then kill in app prefs (note fig and paren kerns first), kern by hand (figs, esp. 1). Or kern s.c.