

THE ELEMENTS

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Each chemical element is characterized by the number of protons, Z , contained in the atomic nucleus. As of 2016, a total of 118 elements have been positively identified and assigned names and symbols. Elements can occur as two or more isotopes, differing in the number of neutrons, N , in the nucleus. An isotope is characterized by the sum of the protons and neutrons in its nucleus, which is called the mass number $A = Z + N$. Including those produced artificially, over 3000 isotopes have been identified, most of which are unstable to radioactive decay. A total of 288 stable isotopes of 84 elements exist on earth.^a

The table below summarizes key properties of the 118 elements. More detailed information can be found in the tables of atomic weights and physical properties. Individual descriptions of the elements follow the table. The definition of the data columns in the table is as follows.

Column heading	Definition
Element	Name of the element; elements are listed alphabetically
Symbol	IUPAC symbol for the element
Z	Atomic number (number of protons)
Atomic wt.	Standard atomic weight; see also "Standard Atomic Weights" table in Section 1
CAS Reg. No.	Chemical Abstract Service Registry Number for the element

Column heading	Definition
State at NTP	Physical state of the element at normal room temperature (25 °C) and one atmosphere pressure
Primary valences	The primary valence (oxidation) states the elements in forming stoichiometric chemical compounds
Mass no. of stable isotopes	Mass number (protons plus neutrons) of stable isotopes
Melting point	Normal melting point in °C; the notation "tp" indicates a triple point, where solid, liquid, and gas are in equilibrium at the indicated pressure; other notes indicate the phase involved
Boiling point	Normal boiling point in °C; This is the temperature at which the liquid phase is in equilibrium with the vapor at a pressure of 760 mmHg (101.325 kPa). A notation "sp" following the value indicates a sublimation point, where the vapor pressure of the solid phase reaches 760 mmHg
Density	Density (mass per unit volume) in g cm^{-3} ; the temperature in °C is indicated by a superscript; values refer to the liquid or solid phase, and all values are true densities, not specific gravities; the number of decimal places gives a rough estimate of the accuracy of the value

^a These numbers include radioactive isotopes whose half-lives are comparable to or greater than the age of the earth, making it possible to define a terrestrial isotopic abundance. See Meija, J., et al., Isotopic Compositions of the Elements 2013, *Pure Appl. Chem.* 2016; 88(3): 293–306.

Element	Symbol	Z	Atomic wt.	CAS Reg. No.	State at NTP	Primary valences	Mass no. of stable isotopes ^a	Melting point in °C	Boiling point in °C	Density in g cm^{-3}
Actinium	Ac	89		7440-34-8	sol	+3		1050	≈3200	10
Aluminum	Al	13	26.9815385(7)	7429-90-5	sol	+3	27	660.323	2519	2.70
Americium	Am	95		7440-35-9	sol	+3, +4, +5, +6		1176	≈2011	12
Antimony	Sb	51	121.760(1)	7440-36-0	sol (gray Sb)	+3, +5	121, 123	630.628	1587	6.68
Argon	Ar	18	39.948(1)	7440-37-1	gas	0	36, 38, 40	-189.34	-185.848	1.395 ^{-185.8} liq
Arsenic	As	33	74.921595(6)	7440-38-2	sol (gray As)	+3, +5, -3	75	817	616 sp	5.75
Astatine	At	85		7440-68-8	sol			302		
Barium	Ba	56	137.327(7)	7440-39-3	sol	+2	130, 132, 134, 135, 136, 137, 138	727	≈1845	3.62
Berkelium	Bk	97		7440-40-6	sol	+3, +4		986		13.25
Beryllium	Be	4	9.0121831(5)	7440-41-7	sol	+2	9	1287	2468	1.85
Bismuth	Bi	83	208.98040(1)	7440-69-9	sol	+3, +5	209	271.402	1564	9.79
Bohrium	Bh	107		54037-14-8	sol ^b	+7 ^b				
Boron	B	5	[10.806, 10.821]	7440-42-8	sol	+3	10, 11	2077	4000	2.34
Bromine	Br	35	[79.901, 79.907]	7726-95-6	liq	+1, +5, -1	79, 81	-7.2	58.8	3.1028
Cadmium	Cd	48	112.414(4)	7440-43-9	sol	+2	106, 108, 110, 111, 112, 113, 114, 116	321.069	767	8.69
Calcium	Ca	20	40.078(4)	7440-70-2	sol	+2	40, 42, 43, 44, 46, 48	842	1484	1.54
Californium	Cf	98		7440-71-3	sol	+3		900		15.1
Carbon	C	6	[12.0096, 12.0106]	7440-44-0	sol (graphite)	+2, +4, -4	12, 13	4489 tp (10.3 MPa)	3825 sp	2.2
Carbon	C	6	[12.0096, 12.0106]	7440-44-0	sol (diamond)	+2, +4, -4	12, 13	4440 (12.4 GPa)		3.513
Cerium	Ce	58	140.116(1)	7440-45-1	sol	+3, +4	136, 138, 140, 142	799	3443	6.770
Cesium	Cs	55	132.90545196(6)	7440-46-2	sol	+1	133	28.5	671	1.873
Chlorine	Cl	17	[35.446, 35.457]	7782-50-5	gas	+1, +5, +7, -1	35, 37	-101.5	-34.04	1.565 ^{-34.0} liq

Element	Symbol	Z	Atomic wt.	CAS Reg. No.	State at NTP	Primary valences	Mass no. of stable isotopes ^a	Melting point in °C	Boiling point in °C	Density in g cm ⁻³
Chromium	Cr	24	51.9961(6)	7440-47-3	sol	+2, +3, +6	50, 52, 53, 54	1907	2671	7.15
Cobalt	Co	27	58.933194(4)	7440-48-4	sol	+2, +3	59	1495	2927	8.86
Copernicium	Cn	112		54084-26-3	liq/gas ^b	+2, +4 ^b				
Copper	Cu	29	63.546(3)	7440-50-8	sol	+1, +2	63, 65	1084.62	2560	8.96
Curium	Cm	96		7440-51-9	sol	+3		1345		13.51
Darmstadtium	Ds	110		54083-77-1	sol ^b	+2,+4,+6 ^b				
Dubnium	Db	105		53850-35-4	sol ^b	+5 ^b				
Dysprosium	Dy	66	162.500(1)	7429-91-6	sol	+3	156, 158, 160, 161, 162, 163, 164	1412	2567	8.55
Einsteinium	Es	99		7429-92-7	sol	+3		860		
Erbium	Er	68	167.259(3)	7440-52-0	sol	+3	162, 164, 166, 167, 168, 170	1529	2868	9.07
Europium	Eu	63	151.964(1)	7440-53-1	sol	+2, +3	151, 153	822	1529	5.24
Fermium	Fm	100		7440-72-4	sol	+3		1527		
Flerovium	Fl	114		54085-16-4	liq/gas ^b	+2, +4 ^b				
Fluorine	F	9	18.998403163(6)	7782-41-4	gas	-1	19	-219.67	-188.11	1.5127 ^{-188.1} liq
Francium	Fr	87		7440-73-5	sol/liq ^b	+1		≈21		
Gadolinium	Gd	64	157.25(3)	7440-54-2	sol	+3	152, 154, 155, 156, 157, 158, 160	1313	3273	7.90
Gallium	Ga	31	69.723(1)	7440-55-3	sol	+3	69, 71	29.7646	2229	5.91
Germanium	Ge	32	72.630(8)	7440-56-4	sol	+2, +4	70, 72, 73, 74, 76	938.25	2833	5.3234
Gold	Au	79	196.966569(5)	7440-57-5	sol	+1, +3	197	1064.18	2836	19.3
Hafnium	Hf	72	178.49(2)	7440-58-6	sol	+4	174, 176, 177, 178, 179, 180	2233	4600	13.3
Hassium	Hs	108		54037-57-9	sol ^b	+8 ^b				
Helium	He	2	4.002602(2)	7440-59-7	gas	0	3, 4		-268.928	0.1250 ^{-268.9} liq
Holmium	Ho	67	164.93033(2)	7440-60-0	sol	+3	165	1472	2700	8.80
Hydrogen	H	1	[1.00784, 1.00811]	1333-74-0	gas	+1	1, 2	-259.16	-252.879	0.07083 ^{-252.9} liq
Indium	In	49	114.818(1)	7440-74-6	sol	+3	113, 115	156.5985	2027	7.31
Iodine	I	53	126.90447(3)	7553-56-2	sol	+1, +5, +7, -1	127	113.7	184.4	4.933
Iridium	Ir	77	192.217(3)	7439-88-5	sol	+3, +4	191, 193	2446	4428	22.562 ²⁰
Iron	Fe	26	55.845(2)	7439-89-6	sol	+2, +3	54, 56, 57, 58	1538	2861	7.87
Krypton	Kr	36	83.798(2)	7439-90-9	gas	0	78, 80, 82, 83, 84, 86	-157.37	-153.415	2.417 ^{-153.4} liq
Lanthanum	La	57	138.90547(7)	7439-91-0	sol	+3	138, 139	920	3464	6.15
Lawrencium	Lr	103		22537-19-5	sol	+3		1627		
Lead	Pb	82	207.2(1)	7439-92-1	sol	+2, +4	204, 206, 207, 208	327.462	1749	11.3
Lithium	Li	3	[6.938, 6.997]	7439-93-2	sol	+1	6, 7	180.50	1342	0.534
Livermorium	Lv	116		54100-71-9	sol ^b	+2, +4 ^b				
Lutetium	Lu	71	174.9668(1)	7439-94-3	sol	+3	175, 176	1663	3402	9.84
Magnesium	Mg	12	[24.304, 24.307]	7439-95-4	sol	+2	24, 25, 26	650	1090	1.74
Manganese	Mn	25	54.938044(3)	7439-96-5	sol	+2, +3, +4, +7	55	1246	2061	7.3
Meitnerium	Mt	109		54038-01-6	sol ^b	+1, +3, +6 ^b				
Mendelevium	Md	101		7440-11-1	sol	+2, +3		827		
Mercury	Hg	80	200.592(3)	7439-97-6	liq	+1, +2	196, 198, 199, 200, 201, 202, 204	-38.8290	356.619	13.53359 ²⁵ liq
Molybdenum	Mo	42	95.95(1)	7439-98-7	sol	+6	92, 94, 95, 96, 97, 98	2622	4639	10.2
Moscovium	Mc	115		54085-64-2	sol ^b	+1, +3 ^b				
Neodymium	Nd	60	144.242(3)	7440-00-8	sol	+3	142, 143, 144, 145, 146, 148, 150	1016	3074	7.01
Neon	Ne	10	20.1797(6)	7440-01-9	gas	0	20, 21, 22	-248.59	-246.046	1.207 ^{-246.0} liq
Neptunium	Np	93		7439-99-8	sol	+3, +4, +5, +6		644	≈3902	20.2
Nickel	Ni	28	58.6934(4)	7440-02-0	sol	+2, +3	58, 60, 61, 62, 64	1455	2913	8.90
Nihonium	Nh	113		54084-70-7	sol ^b	+1, +3 ^b				

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Niobium	Nb	41	92.90637(2)	7440-03-1	sol	+3, +5	93	2477	4741	8.57
Nitrogen	N	7	[14.00643, 14.00728]	7727-37-9	gas	+1, +2, +3, +4, +5, -1, -2, -3	14, 15	-210.0	-195.795	0.8061 ^{-195.8} liq
Nobelium	No	102		10028-14-5	sol	+2, +3		827		
Oganesson	Og	118		54144-19-3	sol ^b	0, +2, +4 ^b				
Osmium	Os	76	190.23(3)	7440-04-2	sol	+3, +4	184, 186, 187, 188, 189, 190, 192	3033	5008	22.587 ²⁰
Oxygen	O	8	[15.99903, 15.99977]	7782-44-7	gas	-2	16, 17, 18	-218.79	-182.962	1.141 ^{-183.0} liq
Palladium	Pd	46	106.42(1)	7440-05-3	sol	+2, +3	102, 104, 105, 106, 108, 110	1554.8	2963	12.0
Phosphorus	P	15	30.973761998(5)	7723-14-0	sol (white P)	+3, +5, -3	31	44.15	280.5	1.823
Phosphorus	P	15	30.973761998(5)	7723-14-0	sol (red P)	+3, +5, -3	31	579.2	431 sp	2.16
Platinum	Pt	78	195.084(9)	7440-06-4	sol	+2, +4	190, 192, 194, 195, 196, 198	1768.2	3825	21.5
Plutonium	Pu	94		7440-07-5	sol	+3, +4, +5, +6		640	3228	19.7
Polonium	Po	84		7440-08-6	sol	+2, +4		254	962	9.20
Potassium	K	19	39.0983(1)	7440-09-7	sol	+1	39, 40, 41	63.5	759	0.89
Praseodymium	Pr	59	140.90766(2)	7440-10-0	sol	+3	141	931	3520	6.77
Promethium	Pm	61		7440-12-2	sol	+3		1042	≈3000	7.26
Protactinium	Pa	91	231.03588(2)	7440-13-3	sol	+4, +5	231	1572		15.4
Radium	Ra	88		7440-14-4	sol	+2		696		5
Radon	Rn	86		10043-92-2	gas	0		-71	-61.7	0.009074 ²⁵ gas
Rhenium	Re	75	186.207(1)	7440-15-5	sol	+4, +6, +7	185, 187	3185	5590	20.8
Rhodium	Rh	45	102.90550(2)	7440-16-6	sol	+3	103	1963	3695	12.4
Roentgenium	Rg	111		54386-24-2	sol ^b	+3, +5, -1 ^b				
Rubidium	Rb	37	85.4678(3)	7440-17-7	sol	+1	85, 87	39.30	688	1.53
Ruthenium	Ru	44	101.07(2)	7440-18-8	sol	+3	100, 101, 102, 104	2333	4147	12.1
Rutherfordium	Rf	104		53850-36-5	sol ^b	+4				
Samarium	Sm	62	150.36(2)	7440-19-9	sol	+2, +3	144, 147, 148, 149, 150, 152, 154	1072	1794	7.52
Scandium	Sc	21	44.955908(5)	7440-20-2	sol	+3	45	1541	2836	2.99
Seaborgium	Sg	106		54038-81-2	sol ^b	+6 ^b				
Selenium	Se	34	78.971(8)	7782-49-2	sol (gray Se)	+4, +6, -2	74, 76, 77, 78, 80, 82	220.8	685	4.809
Silicon	Si	14	[28.084, 28.086]	7440-21-3	sol	+2, +4, -4	28, 29	1414	3265	2.3296
Silver	Ag	47	107.8682(2)	7440-22-4	sol	+1	107, 109	961.78	2162	10.5
Sodium	Na	11	22.98976928(2)	7440-23-5	sol	+1	23	97.794	882.940	0.97
Strontium	Sr	38	87.62(1)	7440-24-6	sol	+2	84, 86, 87, 88	777	1377	2.64
Sulfur	S	16	[32.059, 32.076]	7704-34-9	sol (monoclinic S)	+4, +6, -2	32, 33, 34, 36	115.21	444.61	2.00
Sulfur	S	16	[32.059, 32.076]	7704-34-10	sol (rhombohedral S)	+4, +6, -2	32, 33, 34, 36	95.2 trans monoclinic	444.61	2.07
Tantalum	Ta	73	180.94788(2)	7440-25-7	sol	+5	180, 181	3017	5455	16.4
Technetium	Tc	43		7440-26-8	sol	+4, +6, +7		2157	4262	11
Tellurium	Te	52	127.60(3)	13494-80-9	sol	+4, +6, -2	120, 122, 123, 124, 125, 126, 128, 130	449.51	988	6.232
Tennesine	Ts	117		54101-14-3	sol ^b	+1, +3, +5 ^b				
Terbium	Tb	65	158.92535(2)	7440-27-9	sol	+3	159	1359	3230	8.23
Thallium	Tl	81	[204.382, 204.385]	7440-28-0	sol	+1, +3	203, 205	304	1473	11.8
Thorium	Th	90	232.0377(4)	7440-29-1	sol	+4	232	1750	4785	11.7
Thulium	Tm	69	168.93422(2)	7440-30-4	sol	+3	169	1545	1950	9.32
Tin	Sn	50	118.710(7)	7440-31-6	sol (white Sn)	+2, +4	112, 114, 115, 116, 117, 118, 119, 120, 122, 124	231.928	2586	7.287
Tin	Sn	50	118.710(7)	7440-31-5	sol (gray Sn)	+2, +4	112, 114, 115, 116, 117, 118, 119, 120, 122, 124	13.2 trans white Sn	2586	5.769

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Titanium	Ti	22	47.867(1)	7440-32-6	sol	+2, +3, +4	46, 47, 48, 49, 50	1670	3287	4.506
Tungsten	W	74	183.84(1)	7440-33-7	sol	+6	180, 182, 183, 184, 186	3414	5555	19.3
Uranium	U	92	238.02891(3)	7440-61-1	sol	+3, +4, +5, +6	234, 235, 238	1135	4131	19.1
Vanadium	V	23	50.9415(1)	7440-62-2	sol	+2, +3, +4, +5	50, 51	1910	3407	6.0
Xenon	Xe	54	131.293(6)	7440-63-3	gas	0	124, 126, 128, 129, 130, 131, 132, 134, 136	-111.75	-108.099	2.942 ^{-108.1} liq
Ytterbium	Yb	70	173.045(10)	7440-64-4	sol	+2, +3	168, 170, 171, 172, 173, 174, 176	824	1196	6.90
Yttrium	Y	39	88.90584(2)	7440-65-5	sol	+3	89	1522	3345	4.47
Zinc	Zn	30	65.38(2)	7440-66-6	sol	+2	64, 66, 67, 68, 70	419.527	907	7.134
Zirconium	Zr	40	91.224(2)	7440-67-7	sol	+4	90, 91, 92, 94, 96	1854	4406	6.52

^a Includes radioactive isotopes of very long lifetimes, whose terrestrial abundance is effectively stable.

^b Predicted

Actinium — (Gr. *aktis*, *aktinos*, beam of ray), Ac. Discovered by Andre Debierne in 1899 and independently by F. Giesel in 1902. Occurs naturally in association with uranium minerals. Thirty-seven isotopes and isomers are now recognized. All are radioactive. Actinium-227, a decay product of uranium-235, is an alpha and beta emitter with a 21.77-year half-life. Its principal decay products are thorium-227 (18.72-day half-life), radium-223 (11.4-day half-life), and a number of short-lived products including radon, bismuth, polonium, and lead isotopes. In equilibrium with its decay products, it is a powerful source of alpha rays. Actinium metal has been prepared by the reduction of actinium fluoride with lithium vapor at about 1100 to 1300 °C. The chemical behavior of actinium is similar to that of the rare earths, particularly lanthanum. Purified actinium comes into equilibrium with its decay products at the end of 185 days, and then decays according to its 21.77-year half-life. It is about 150 times as active as radium, making it of value in the production of neutrons.

Aluminum — (L. *alumen*, *alum*), Al. The ancient Greeks and Romans used *alum* in medicine as an astringent, and as a mordant in dyeing. In 1761 de Morveau proposed the name *alumine* for the base in alum, and Lavoisier, in 1787, thought this to be the oxide of a still undiscovered metal. Wöhler is generally credited with having isolated the metal in 1827, although an impure form was prepared by Oersted two years earlier. In 1807, Davy proposed the name *aluminium* for the metal, undiscovered at that time, and later agreed to change it to *aluminium*. Shortly thereafter, the name *aluminium* was adopted to conform with the "ium" ending of most elements, and this spelling is now in use elsewhere in the world. *Aluminium* was also the accepted spelling in the U.S. until 1925, at which time the American Chemical Society officially decided to use the name *aluminum* thereafter in their publications. The method of obtaining aluminum metal by the electrolysis of alumina dissolved in cryolite was discovered in 1886 by Hall in the U.S. and at about the same time by Heroult in France. Cryolite, a natural ore found in Greenland, is no longer widely used in commercial production, but has been replaced by an artificial mixture of sodium,

aluminum, and calcium fluorides. Bauxite, an impure hydrated oxide ore, is found in large deposits in Jamaica, Australia, Suriname, Guyana, Russia, Arkansas, and elsewhere. The Bayer process is most commonly used today to refine bauxite so it can be accommodated in the Hall–Heroult refining process used to make most aluminum. Aluminum can now be produced from clay, but the process is not economically feasible at present. Aluminum is the most abundant metal to be found in the Earth's crust (8.1%), but is never found free in nature. In addition to the minerals mentioned above, it is found in feldspars, granite, and in many other common minerals. Natural aluminum is made of one isotope, ²⁷Al. Pure aluminum, a silvery-white metal, possesses many desirable characteristics. It is light, nontoxic, has a pleasing appearance, can easily be formed, machined, or cast, has a high thermal conductivity, and has excellent corrosion resistance. It is nonmagnetic and nonsparking, stands second among metals in the scale of malleability, and sixth in ductility. It is extensively used for kitchen utensils, outside building decoration, and in thousands of industrial applications where a strong, light, easily constructed material is needed. Although its electrical conductivity is only about 60% that of copper, it is used in electrical transmission lines because of its light weight. Pure aluminum is soft and lacks strength, but it can be alloyed with small amounts of copper, magnesium, silicon, manganese, and other elements to impart a variety of useful properties. These alloys are of vital importance in the construction of modern aircraft and rockets. Aluminum, evaporated in a vacuum, forms a highly reflective coating for both visible light and radiant heat. These coatings soon form a thin layer of the protective oxide and do not deteriorate as do silver coatings. They have found application in coatings for telescope mirrors, in making decorative paper, packages, toys, and in many other uses. The compounds of greatest importance are aluminum oxide, the sulfate, and the soluble sulfate with potassium (alum). The oxide, alumina, occurs naturally as ruby, sapphire, corundum, and emery, and is used in glassmaking and refractories. Synthetic ruby and sapphire have found application in the construction of lasers.

Americium — (the Americas), Am. Americium was the fourth transuranium element to be discovered; the isotope ^{241}Am was identified by Seaborg, James, Morgan, and Ghiorso late in 1944 at the wartime Metallurgical Laboratory of the University of Chicago as the result of successive neutron capture reactions by plutonium isotopes in a nuclear reactor. Since the isotope ^{241}Am can be prepared in relatively pure form by extraction as a decay product over a period of years from strongly neutron-bombarded plutonium, ^{241}Pu , this isotope is used for much of the chemical investigation of this element. Better suited is the isotope ^{243}Am due to its longer half-life (7370 years as compared to 432.2 years for ^{241}Am). A mixture of the isotopes ^{241}Am , ^{242}Am , and ^{243}Am can be prepared by intense neutron irradiation of ^{241}Am according to the reactions $^{241}\text{Am} (n, \gamma) \rightarrow ^{242}\text{Am} (n, \gamma) \rightarrow ^{243}\text{Am}$. Nearly isotopically pure ^{243}Am can be prepared by a sequence of neutron bombardments and chemical separations starting with ^{242}Pu . Twenty-three radioactive isotopes and isomers are now recognized. Americium metal has been prepared by reducing the trifluoride with barium vapor at 1000 to 1200 °C or reducing the dioxide by lanthanum metal. The luster of freshly prepared americium metal is white and more silvery than plutonium or neptunium prepared in the same manner. It appears to be more malleable than uranium or neptunium and tarnishes slowly in dry air at room temperature. Americium is thought to exist in two forms: an alpha form which has a double hexagonal close-packed structure and a loose-packed cubic beta form. Americium must be handled with great care to avoid personal contamination. As little as 0.03 μCi of ^{241}Am is the maximum permissible total body burden. The alpha activity from ^{241}Am is about three times that of radium. When gram quantities of ^{241}Am are handled, the intense gamma activity makes exposure a serious problem. Americium dioxide, AmO_2 , is the most important oxide. AmF_3 , AmF_4 , AmCl_3 , AmBr_3 , AmI_3 , and other compounds have been prepared. The isotope ^{241}Am has been used as a portable source for gamma radiography. It has also been used as a radioactive glass thickness gage for the flat glass industry and as a source of ionization for smoke detectors.

Antimony — (Gr. *anti* plus *monos* - a metal not found alone), Sb. Antimony was recognized in compounds by the ancients and was known as a metal at the beginning of the 17th century and possibly much earlier. It is not abundant, but is found in over 100 mineral species. It is sometimes found native, but more frequently as the sulfide, *stibnite* (Sb_2S_3); it is also found as antimonides of the heavy metals, and as oxides. It is extracted from the sulfide by roasting to the oxide, which is reduced by salt and scrap iron; from its oxides it is also prepared by reduction with carbon. Two allotropic forms of antimony exist: the normal stable, metallic form (gray antimony), and the amorphous black form. The so-called explosive antimony is an ill-defined material always containing an appreciable amount of halogen; therefore, it no longer warrants consideration as a separate allotrope. The yellow form, obtained by oxidation of *stibine*, SbH_3 , is probably impure, and is not a distinct form. Natural antimony is made of two stable isotopes, ^{121}Sb and ^{123}Sb . Metallic antimony is an extremely

brittle metal of a flaky, crystalline texture. It is bluish white and has a metallic luster. It is not acted on by air at room temperature, but burns brilliantly when heated with the formation of white fumes of Sb_2O_3 . It is a poor conductor of heat and electricity, and has a hardness of 3 to 3.5. Antimony, available commercially with a purity of 99.999 + %, is finding use in semiconductor technology for making infrared detectors, diodes, and Hall-effect devices. Commercial-grade antimony is widely used in alloys with percentages ranging from 1% to 20%. It greatly increases the hardness and mechanical strength of lead. Batteries, antifriction alloys, type metal, small arms and tracer bullets, cable sheathing, and minor products use about half the metal produced. Compounds taking up the other half are oxides, sulfides, sodium antimonate, and antimony trichloride. These are used in manufacturing flame-proofing compounds, paints, ceramic enamels, glass, and pottery. Tartar emetic (hydrated potassium antimonyl tartrate) has been used in medicine. Antimony and many of its compounds are toxic.

Argon — (Gr. *argos*, inactive), Ar. Its presence in air was suspected by Cavendish in 1785, discovered by Lord Rayleigh and Sir William Ramsay in 1894. The gas is prepared by fractionation of liquid air, the atmosphere containing 0.934% argon. The atmosphere of Mars contains 1.6% of ^{40}Ar and 5 ppm of ^{36}Ar . Argon is two and one half times as soluble in water as nitrogen, having about the same solubility as oxygen. It is recognized by the characteristic lines in the red end of the spectrum. It is used in electric light bulbs and in fluorescent tubes at a pressure of about 400 Pa, and in filling photo tubes, glow tubes, etc. Argon is also used as an inert gas shield for arc welding and cutting; as a blanket for the production of titanium and other reactive elements; and as a protective atmosphere for growing silicon and germanium crystals. Argon is colorless and odorless, both as a gas and liquid. It is available in high-purity form. Argon is considered to be more inert than the other rare gases, although a compound HArF has been prepared at extremely low temperatures. However, it does form a hydrate having a dissociation pressure of 105 atm at 0 °C. Ion molecules such as $(\text{ArKr})^+$, $(\text{ArXe})^+$, $(\text{NeAr})^+$ have been observed spectroscopically. Argon also forms a clathrate with β -hydroquinone. This clathrate is stable and can be stored for a considerable time, but a true chemical bond does not exist.

Arsenic — (L. *arsenicum*, Gr. *arsenikon*, yellow orpiment, identified with *arsenikos*, male, from the belief that metals were different sexes; Arabic, *Az-zernikh*, the orpiment from Persian *zerni-zar*, gold), As. It is believed that Albertus Magnus obtained the element in 1250 A.D. In 1649 Schroeder published two methods of preparing the element. It is found native, in the sulfides *realgar* and *orpiment*, as arsenides and sulfarsenides of heavy metals, as the oxide, and as arsenates. *Mispickel*, arsenopyrite, (FeSAs) is the most common mineral, from which on heating the arsenic sublimes leaving ferrous sulfide. The most common form of the element, gray arsenic, is a steel gray, very brittle, crystalline, semimetallic solid; it tarnishes in air, and when heated is rapidly oxidized to arsenous oxide (As_2O_3) with the odor of garlic. Two other allotropes, black arsenic and yellow arsenic, can

be made by condensing arsenic vapor. Arsenic and its compounds are extremely poisonous. Arsenic is also used in bronzing, pyrotechny, and for hardening and improving the sphericity of shot. The most important compounds are white arsenic (As_2O_3); the sulfide; Paris green, $3\text{Cu}(\text{AsO}_2)_2 \cdot \text{Cu}(\text{C}_2\text{H}_3\text{O}_2)_2$; calcium arsenate; and lead arsenate. The last three have been used as agricultural insecticides and poisons. Marsh's test for arsenic compounds makes use of the formation and ready decomposition of arsine (AsH_3); it has long been used in forensics. Arsenic is finding increasing uses as a doping agent in solid-state devices such as transistors. Gallium arsenide is used as a laser material and in various electronic devices.

Astatine — (Gr. *astatos*, unstable), At. Synthesized in 1940 by D.R. Corson, K. R. MacKenzie, and E. Segre at the University of California by bombarding bismuth with alpha particles. The longest-lived isotope, ^{210}At , has a half-life of only 8.1 hours. Over 50 other isotopes and isomers are now known. Minute quantities of ^{215}At , ^{218}At , and ^{219}At exist in equilibrium in nature with naturally occurring uranium and thorium isotopes, and traces of ^{217}At are in equilibrium with ^{233}U and ^{239}Np resulting from interaction of thorium and uranium with naturally produced neutrons. The total amount of astatine present in the Earth's crust, however, is probably less than 30 g. Only about 0.05 μg of astatine has been prepared to date. Mass spectrometers have been used to confirm that this highly radioactive halogen behaves chemically very much like other halogens, particularly iodine. The interhalogen compounds AtI , AtBr , and AtCl are known to form, but it is not yet known if astatine forms diatomic astatine molecules. HAt and CH_3At (methyl astatide) have been detected. Astatine is said to be more metallic than iodine, and, like iodine, it probably accumulates in the thyroid gland.

Barium — (Gr. *barys*, heavy), Ba. Baryta was distinguished from lime by Scheele in 1774; the element was discovered by Sir Humphrey Davy in 1808. It is found only in combination with other elements, chiefly in *barite* or *heavy spar* (sulfate) and *witherite* (carbonate) and is prepared by electrolysis of the chloride. Large deposits of barite are found in China, Germany, India, Morocco, and in the U.S. Barium is a metallic element, soft, and when pure is silvery white like lead; it belongs to the alkaline earth group, resembling calcium chemically. The metal oxidizes very easily and should be kept under petroleum or other suitable oxygen-free liquids to exclude air. It is decomposed by water or alcohol. The metal is used as a "getter" in vacuum tubes. The most important compounds are the peroxide (BaO_2), chloride, sulfate, carbonate, nitrate, and chlorate. Lithopone, a pigment containing barium sulfate and zinc sulfide, has good covering power, and does not darken in the presence of sulfides. The sulfate, as permanent white or *blanc fixe*, is also used in paint, in x-ray diagnostic work, and in glassmaking. *Barite* is extensively used as a weighting agent in oil well drilling fluids, and also in making rubber. The carbonate has been used as a rat poison, while the nitrate and chlorate give green colors in pyrotechny. The impure sulfide phosphoresces after exposure to the light. All barium compounds that are water or acid soluble are poisonous.

Berkelium — (*Berkeley*, home of the University of California), Bk. Berkelium, the eighth member of the actinide transition series, was discovered in December 1949 by Thompson, Ghiorso, and Seaborg, and was the fifth transuranium element synthesized. It was produced by cyclotron bombardment of milligram amounts of ^{241}Am with helium ions at Berkeley, California. The first isotope produced had a mass number of 243 and decayed with a half-life of 4.5 hours. Thirteen isotopes are now known and have been synthesized. The existence of ^{249}Bk , with a half-life of 320 days, makes it feasible to isolate berkelium in weighable amounts so that its properties can be investigated with macroscopic quantities. One of the first visible amounts of a pure berkelium compound, berkelium chloride, was produced in 1962. It weighed 3 ng. Elemental berkelium is expected to be a silvery metal, easily soluble in dilute mineral acids, and readily oxidized by air or oxygen at elevated temperatures to form the oxide. X-ray diffraction methods have been used to identify the following compounds: BkO_2 , BkO_3 , BkF_3 , BkCl , and BkOCl . Berkelium most likely resembles terbium with respect to chemical properties. As with other actinide elements, berkelium tends to accumulate in the skeletal system. Because of its rarity, berkelium presently has no commercial or technological use.

Beryllium — (Gr. *beryllos*, *beryl*; also called Glucinium or Glucinum, Gr. *glykys*, sweet), Be. Discovered as the oxide by Vauquelin in beryl and in emeralds in 1798. The metal was isolated in 1828 by Wöhler and by Bussy independently by the action of potassium on beryllium chloride. Beryllium is found in some 30 mineral species, the most important of which are *bertrandite*, *beryl*, *chrysoberyl*, and *phenacite*. *Aquamarine* and *emerald* are precious forms of *beryl*. Beryllium minerals are found in the U.S., Brazil, Russia, Kazakhstan, and elsewhere. Colombia is known for its emeralds. *Beryl* ($3\text{BeO} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$) and *bertrandite* ($4\text{BeO} \cdot 2\text{SiO}_2 \cdot \text{H}_2\text{O}$) are the most important commercial sources of the element and its compounds. Most of the metal is now prepared by reducing beryllium fluoride with magnesium metal. Beryllium metal did not become readily available to industry until 1957. The metal, steel gray in color, has many desirable properties. It is one of the lightest of all metals, and has one of the highest melting points of the light metals. Its modulus of elasticity is about one third greater than that of steel. It resists attack by concentrated nitric acid, has excellent thermal conductivity, and is nonmagnetic. It has a high permeability to x-rays, and when bombarded by alpha particles, as from radium or polonium, neutrons are produced in the ratio of about 30 neutrons/million alpha particles. At ordinary temperatures beryllium resists oxidation in air, although its ability to scratch glass is probably due to the formation of a thin layer of the oxide. Beryllium is used as an alloying agent in producing beryllium copper, which is extensively used for springs, electrical contacts, spot-welding electrodes, and non-sparking tools. It has found application as a structural material for high-speed aircraft, missiles, spacecraft, and communication satellites. It was used in the windshield frame, brake discs, support beams, and other structural components of the space shuttle. Because beryllium is relatively transparent to x-rays, ultrathin Be-foil is finding

use in x-ray lithography for reproduction of microminiature integrated circuits. Natural beryllium is 100% ^9Be . Beryllium is used in nuclear reactors as a reflector or moderator for it has a low thermal neutron absorption cross section. It is used in gyroscopes, computer parts, and instruments where lightness, stiffness, and dimensional stability are required. The oxide has a very high-melting point and is also used in nuclear technology and ceramic applications. Beryllium and its salts are toxic and should be handled with the greatest of care. They should not be tasted to verify the sweetish nature of beryllium (as did early experimenters). The metal, its alloys, and its salts can be handled safely if certain work codes are observed, but no attempt should be made to work with beryllium before becoming familiar with proper safeguards.

Bismuth — (Ger. *Weisse Masse*, white mass; later *Wisuth* and *Bisemutum*), Bi. In early times bismuth was confused with tin and lead. Claude Geoffroy the Younger showed it to be distinct from lead in 1753. It is a white crystalline, brittle metal with a pinkish tinge. It occurs native. The most important ores are *bismuthinite* or bismuth glance (Bi_2S_3) and *bismite* (Bi_2O_3). Peru, Japan, Mexico, Bolivia, and Canada are major bismuth producers. Much of the bismuth produced in the U.S. is obtained as a by-product in refining lead, copper, tin, silver, and gold ores. Bismuth is the most diamagnetic of all metals, and the thermal conductivity is lower than any metal, except mercury. It has a high electrical resistance, and has the highest Hall effect of any metal (i.e., greatest increase in electrical resistance when placed in a magnetic field). "Bismanol" is a permanent magnet of high coercive force, made of MnBi. Bismuth expands 3.32% on solidification. This property makes bismuth alloys particularly suited to the making of sharp castings of objects subject to damage by high temperatures. With other metals such as tin, cadmium, etc., bismuth forms low-melting alloys that are extensively used for safety devices in fire detection and extinguishing systems. Bismuth is used in producing malleable irons and is finding use as a catalyst for making acrylic fibers. When bismuth is heated in air it burns with a blue flame, forming yellow fumes of the oxide. The metal is also used as a thermocouple material, and has found application as a carrier for U^{235} or U^{233} fuel in atomic reactors. Its soluble salts are characterized by forming insoluble basic salts on the addition of water, a property sometimes used in detection work. Bismuth oxychloride is used extensively in cosmetics. Bismuth subnitrate and subcarbonate are used in medicine. Natural bismuth contains only one isotope ^{209}Bi .

Bohrium — (Named after Niels Bohr [1885–1962], Danish atomic and nuclear physicist), Bh. Bohrium is expected to have chemical properties similar to rhenium. This element was synthesized and unambiguously identified in 1981 using the Universal Linear Accelerator (UNILAC) at the Gesellschaft für Schwerionenforschung (G.S.I.) in Darmstadt, Germany. The discovery team was led by Armbruster and Münzenberg. The reaction producing the element was proposed and applied earlier by a Dubna Group led by Oganessian in 1976. A target of ^{209}Bi was bombarded by a beam of ^{54}Cr ions. In 1983 experiments at Dubna using the 157-inch cyclotron, produced ^{262}Bh

by the reaction $^{209}\text{Bi} + ^{54}\text{Cr}$. IUPAC adopted the name Bohrium with the symbol Bh for Element 107 in August 1997. Ten isotopes of bohrium are now recognized, two of which have lifetimes of around 1 minute.

Boron — (Ar. *Buraq*, Pers. *Burahi*), B. Boron compounds have been known for thousands of years, but the element was not discovered until 1808 by Sir Humphry Davy and by Gay-Lussac and Thenard. The element is not found free in nature, but occurs as orthoboric acid, usually in certain volcanic spring waters, and as borates in *borax* and *colemanite*. *Ulexite*, another boron mineral, is interesting as it is nature's own version of fiber optics. Important sources of boron are the ores *rasorite* (*kernite*) and *tincal* (*borax ore*). Both of these ores are found in the Mojave Desert. *Tincal* is the most important source of boron from the Mojave. Extensive *borax* deposits are also found in Turkey. Boron exists naturally as 19.9% ^{10}B isotope and 80.1% ^{11}B isotope. High-purity crystalline boron may be prepared by the vapor phase reduction of boron trichloride or tribromide with hydrogen on electrically heated filaments. The impure, or amorphous, boron, a brownish-black powder, can be obtained by heating the trioxide with magnesium powder. Boron of 99.9999% purity has been produced and is available commercially. Elemental boron has an energy band gap of 1.50 to 1.56 eV, which is higher than that of either silicon or germanium. It has interesting optical characteristics, transmitting portions of the infrared, and is a poor conductor of electricity at room temperature, but a good conductor at high temperature. Amorphous boron is used in pyrotechnic flares to provide a distinctive green color, and in rockets as an igniter. By far the most commercially important boron compound in terms of dollar sales is $\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$. This pentahydrate is used in very large quantities in the manufacture of insulation fiberglass and sodium perborate bleach. Boric acid is also an important boron compound with major markets in textile fiberglass and in cellulose insulation as a flame retardant. Next in order of importance is borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$) which is used principally in laundry products. Use of borax as a mild antiseptic is minor in terms of dollars and tons. Boron compounds are also extensively used in the manufacture of borosilicate glasses. The isotope ^{10}B is used as a control for nuclear reactors as a shield for nuclear radiation, and in instruments used for detecting neutrons. Boron nitride has remarkable properties and can be used to make a material as hard as diamond. The nitride also behaves like an electrical insulator but conducts heat like a metal. It also has lubricating properties similar to graphite. The hydrides are easily oxidized with considerable energy liberation, and have been studied for use as rocket fuels. Demand is increasing for boron filaments, a high-strength, lightweight material chiefly employed for advanced aerospace structures. Boron is similar to carbon in that it has a capacity to form stable covalently bonded molecular networks. Carboranes, metalboranes, phosphacarboranes, and other families comprise thousands of compounds. Elemental boron and the borates are not considered to be toxic, and they do not require special care in handling. However, some of the more exotic boron hydrogen compounds are toxic and do require care.

Bromine — (Gr. *bromos*, stench), Br. Discovered by Balard in 1826, but not prepared in quantity until 1860. A member of the halogen group of elements, it is obtained from natural brines from wells in Michigan and Arkansas. Little bromine is extracted today from seawater, which contains only about 85 ppm. Bromine is the only liquid nonmetallic element. It is a heavy, mobile, reddish-brown liquid, volatilizing readily at room temperature to a red vapor with a strong disagreeable odor, resembling chlorine, and having a very irritating effect on the eyes and throat. It is readily soluble in water or carbon disulfide, forming a red solution; is less active than chlorine but more so than iodine. It unites readily with many elements and has a bleaching action; when spilled on the skin it produces painful sores. It presents a serious health hazard, and maximum safety precautions should be taken when handling it. Much of the bromine output in the U.S. was used in the production of ethylene dibromide, a lead scavenger used in making gasoline antiknock compounds. Since lead in gasoline was eliminated because of environmental considerations, production of bromine has decreased. Bromine is also used in making fumigants, flameproofing agents, water purification compounds, dyes, medicinals, sanitizers, etc. Organic bromides are also important.

Cadmium — (L. *cadmia*; Gr. *kadmeia* - ancient name for calamine, zinc carbonate), Cd. Discovered by Stromeyer in 1817 from an impurity in zinc carbonate. Cadmium most often occurs in small quantities associated with zinc ores, such as *sphalerite* (ZnS). *Greenockite* (CdS) is the only mineral of any consequence bearing cadmium. Almost all cadmium is obtained as a by-product in the treatment of zinc, copper, and lead ores. It is a soft, bluish-white metal which is easily cut with a knife. It is similar in many respects to zinc. It is a component of some of the lowest melting alloys; it is used in bearing alloys with low coefficients of friction and great resistance to fatigue; it is used extensively in electroplating, which accounts for about 60% of its use. It is also used in many types of solder, for standard E.M.F. cells, for Ni-Cd batteries, and as a barrier to control atomic fission. The market for Ni-Cd batteries has grown significantly. Cadmium compounds are used in blue and green phosphors for color TV tubes. It forms a number of salts, of which the sulfate is most common; the sulfide is used as a yellow pigment. Cadmium and solutions of its compounds are toxic. Failure to appreciate the toxic properties of cadmium may cause workers to be unwittingly exposed to dangerous fumes. Some silver solders, for example, contain cadmium and should be handled with care. Serious toxicity problems have been found from long-term exposure and work with cadmium plating baths. Cadmium is present in certain phosphate rocks. This has raised concerns that the long-term use of certain phosphate fertilizers might pose a health hazard from levels of cadmium that might enter the food chain. At one time the International Conference on Weights and Measures defined the meter in terms of the wavelength of the red cadmium spectral line.

Calcium — (L. *calx*, lime), Ca. Though lime was prepared by the Romans in the first century under the name *calx*, the metal was not discovered until 1808. After learning that Berzelius and Pontin prepared calcium amalgam by

electrolyzing lime in mercury, Davy was able to isolate the impure metal. Calcium is a metallic element, fifth in abundance in the Earth's crust, of which it forms more than 3%. It is an essential constituent of leaves, bones, teeth, and shells. Never found in nature uncombined, it occurs abundantly as *limestone* (CaCO_3), *gypsum* ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), and *fluorite* (CaF_2); *apatite* is the fluorophosphate or chlorophosphate of calcium. The metal has a silvery color, is rather hard, and is prepared by electrolysis of the fused chloride to which calcium fluoride is added to lower the melting point. Chemically it is one of the alkaline earth elements; it readily forms a white coating of oxide in air, reacts with water, burns with a yellow-red flame, largely forming the oxide. The metal is used as a reducing agent in preparing other metals such as thorium, uranium, zirconium, etc., and is used as a deoxidizer, desulfurizer, and inclusion modifier for various ferrous and nonferrous alloys. It is also used as an alloying agent for aluminum, beryllium, copper, lead, and magnesium alloys, and serves as a "getter" for residual gases in vacuum tubes. Its natural and prepared compounds are widely used. Quicklime (CaO), made by heating limestone and changed into slaked lime by the careful addition of water, is the great cheap base of the chemical industry with countless uses. Mixed with sand it hardens as mortar and plaster by taking up carbon dioxide from the air. Calcium from limestone is an important element in Portland cement. The solubility of the carbonate in water containing carbon dioxide causes the formation of caves with stalactites and stalagmites and is responsible for hardness in water. Other important compounds are the carbide (CaC_2), chloride (CaCl_2), cyanamide (CaCN_2), hypochlorite (Ca(OCl)_2), nitrate ($\text{Ca(NO}_3)_2$), and sulfide (CaS). Calcium sulfide is phosphorescent after being exposed to light.

Californium — (State and University of California), Cf. Californium, the sixth transuranium element to be discovered, was produced by Thompson, Street, Ghiorso, and Seaborg in 1950 by bombarding microgram quantities of ^{242}Cm with 35 MeV helium ions in the Berkeley 60-inch cyclotron. The existence of the isotopes ^{249}Cf , ^{250}Cf , ^{251}Cf , and ^{252}Cf makes it feasible to isolate californium in weighable amounts so that its properties can be investigated. Californium-252 is a very strong neutron emitter. One microgram releases 170 million neutrons per minute, which presents biological hazards. Proper safeguards should be used in handling californium. Twenty isotopes of californium are now recognized. ^{249}Cf and ^{252}Cf have half-lives of 351 years and 900 years, respectively. Californium (III) is the only ion stable in aqueous solutions, all attempts to reduce or oxidize californium (III) having failed. In 1960 a few tenths of a microgram of californium trichloride, CfCl_3 , californium oxychloride, CfOCl , and californium oxide, Cf_2O_3 , were first prepared. Because californium is a very efficient source of neutrons, many new uses are expected for it. It has already found use in neutron moisture gages and in well-logging (the determination of water and oil-bearing layers). It is also being used as a portable neutron source for discovery of metals such as gold or silver by on-the-spot activation analysis.

Carbon — (L. *carbo*, charcoal), C. Carbon, an element of prehistoric discovery, is very widely distributed in nature.

It is found in abundance in the sun, stars, comets, and atmospheres of most planets. Carbon in the form of microscopic diamonds is found in some meteorites. Natural diamonds are found in *kimberlite* or *lamproite* of ancient formations called “pipes,” such as found in South Africa, Arkansas, and elsewhere. Diamonds are being recovered from the ocean floor off the Cape of Good Hope. About 30% of all industrial diamonds used in the U.S. are now made synthetically. The energy of the sun and stars can be attributed at least in part to the carbon-nitrogen cycle of nuclear reactions. Carbon is found free in nature in three allotropic forms: amorphous, graphite, and diamond. Graphite is one of the softest known materials while diamond is one of the hardest. Graphite exists in two forms: alpha and beta. These have identical physical properties, except for their crystal structure. Naturally occurring graphites are reported to contain as much as 30% of the rhombohedral (beta) form, whereas synthetic materials contain only the alpha form. The hexagonal alpha type can be converted to the beta by mechanical treatment, and the beta form reverts to the alpha on heating it above 1000 °C. Fullerenes or “buckyballs” have a number of unusual properties. These molecules, consisting of 60 or 70 carbon atoms linked together, are capable of withstanding great pressure and trapping foreign atoms inside their network of carbon. Fullerene films doped with alkali atoms remain superconductive at temperatures as high as 45 K. In combination, carbon is found as carbon dioxide in the atmosphere of the Earth and dissolved in all natural waters. On average, the earth's atmosphere contains about 0.04% CO₂, while the atmosphere of Mars contains 95.32% CO₂. It is a component of great rock masses in the form of carbonates of calcium (limestone), magnesium, and iron. Coal, petroleum, and natural gas are chiefly hydrocarbons. Carbon is unique among the elements in the vast number and variety of compounds it can form. With hydrogen, oxygen, nitrogen, and other elements, it forms a very large number of compounds, carbon atom often being linked to carbon atom. Many thousands of carbon compounds are vital to organic and life processes. Without carbon, the basis for life as we know it would be impossible. While it has been thought that silicon might take the place of carbon in forming a host of similar compounds, it is now not possible to form stable compounds with very long chains of silicon atoms. Some of the compounds of carbon of greatest industrial importance are carbon dioxide (CO₂), carbon monoxide (CO), carbon disulfide (CS₂), chloroform (CHCl₃), carbon tetrachloride (CCl₄), methane (CH₄), ethylene (C₂H₄), acetylene (C₂H₂), benzene (C₆H₆), ethyl alcohol (C₂H₅OH), acetic acid (CH₃COOH), and their derivatives. Natural carbon consists of 98.93% ¹²C and 1.07% ¹³C. In 1961 the International Union of Pure and Applied Chemistry adopted the isotope carbon-12 as the basis for atomic weights. Carbon-14, an isotope with a half-life of 5715 years, has been widely used to date such materials as wood, archeological specimens, etc. A brittle form of carbon, known as “glassy” or vitreous carbon, has been developed. It has a high resistance to corrosion, has good thermal stability, and is structurally impermeable to both gases and liquids. It has a randomized structure, making it useful in applications such as

crystal growing, crucibles for high-temperature use, prosthetic devices, etc.

Cerium — (named for the asteroid *Ceres*, which was discovered in 1801 only 2 years before the element), Ce. Discovered in 1803 by Klaproth and by Berzelius and Hisinger; metal prepared by Hillebrand and Norton in 1875. Cerium is the most abundant of the metals of the so-called rare earths. It is found in a number of minerals including *allanite* (also known as *orthite*), *monazite*, *bastnasite*, *cerite*, and *samarskite*. Monazite and bastnasite are presently the two most important sources of cerium. Large deposits of monazite found on the beaches of Travancore, India, in river sands in Brazil, and deposits of *allanite* in the western United States, and *bastnasite* in Southern California will supply cerium, thorium, and the other rare-earth metals for many years to come. Metallic cerium is prepared by metallothermic reduction techniques, such as by reducing cerous fluoride with calcium, or by electrolysis of molten cerous chloride or other cerous halides. The metallothermic technique is used to produce high-purity cerium. Cerium is especially interesting because of its variable electronic structure. The energy of the inner 4f level is nearly the same as that of the outer or valence electrons, and only small amounts of energy are required to change the relative occupancy of these electronic levels. This gives rise to dual valency states. For example, a volume change of about 10% occurs when cerium is subjected to high pressures or low temperatures. It appears that the valence changes from about 3 to 4 when it is cooled or compressed. The low-temperature behavior of cerium is complex. Four allotropic modifications are thought to exist: cerium at room temperature and at atmospheric pressure is known as γ cerium. Upon cooling to -16°C , γ cerium changes to β cerium. The remaining γ cerium starts to change to α cerium when cooled to -172°C , and the transformation is complete at -269°C . α Cerium has a density of 8.16; δ cerium exists above 726°C . At atmospheric pressure, liquid cerium is more dense than its solid form at the melting point. Cerium is an iron-gray lustrous metal. It is malleable, and oxidizes very readily at room temperature, especially in moist air. Except for europium, cerium is the most reactive of the “rare-earth” metals. It slowly decomposes in cold water, and rapidly in hot water. Alkali solutions and dilute and concentrated acids attack the metal rapidly. The pure metal is likely to ignite if scratched with a knife. Ceric salts are orange red or yellowish; cerous salts are usually white. Cerium is a component of misch metal, which is extensively used in the manufacture of pyrophoric alloys for cigarette lighters, etc. Natural cerium is stable and contains four isotopes. Thirty-two other radioactive isotopes and isomers are known. While cerium is not radioactive, the impure commercial grade may contain traces of thorium, which is radioactive. The oxide is an important constituent of incandescent gas mantles and it is emerging as a hydrocarbon catalyst in “self-cleaning” ovens. In this application it can be incorporated into oven walls to prevent the collection of cooking residues. As ceric sulfate it finds extensive use as a volumetric oxidizing agent in quantitative analysis. Cerium compounds are used in the manufacture of glass, both as a component and as a decolorizer.

The oxide is finding increased use as a glass polishing agent instead of rouge, for it is much faster than rouge in polishing glass surfaces. Cerium compounds are finding use in automobile exhaust catalysts. Cerium is also finding use in making permanent magnets. Cerium, with other rare earths, is used in carbon-arc lighting, especially in the motion picture industry. It is also finding use as an important catalyst in petroleum refining and in metallurgical and nuclear applications. In small lots, cerium costs about \$5/g (99.9%).

Cesium — (*L. caesius*, sky blue), Cs. Cesium was discovered spectroscopically by Bunsen and Kirchhoff in 1860 in mineral water from Durkheim. Cesium, an alkali metal, occurs in *lepidolite*, *pollucite* (a hydrated silicate of aluminum and cesium), and in other sources. One of the world's richest sources of cesium is located at Bernic Lake, Manitoba. The deposits are estimated to contain 300,000 tons of pollucite, averaging 20% cesium. It can be isolated by electrolysis of the fused cyanide and by a number of other methods. Very pure, gas-free cesium can be prepared by thermal decomposition of cesium azide. The metal is characterized by a spectrum containing two bright lines in the blue along with several others in the red, yellow, and green. It is silvery white, soft, and ductile. It is the most electropositive and most alkaline element. Cesium, gallium, and mercury are the only three metals that are liquid near room temperature. Cesium reacts explosively with cold water, and reacts with ice at temperatures above -116°C . Cesium hydroxide, the strongest base known, attacks glass. Because of its great affinity for oxygen the metal is used as a "getter" in electron tubes. It is also used in photoelectric cells, as well as a catalyst in the hydrogenation of certain organic compounds. The metal has recently found application in ion propulsion systems. Cesium is used in atomic clocks; a second of time is now defined as being the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom. Its chief compounds are the chloride and the nitrate.

Chlorine — (*Gr. chloros*, greenish yellow), Cl. Discovered in 1774 by Scheele, who thought it contained oxygen; named in 1810 by Davy, who insisted it was an element. In nature it is found in the combined state only, chiefly with sodium and potassium as common salt (NaCl), *carnallite* ($\text{KMgCl}_3 \cdot 6\text{H}_2\text{O}$), and *sylvite* (KCl). It is a member of the halogen (salt-forming) group of elements and is obtained from chlorides by the action of oxidizing agents and more often by electrolysis; it is a greenish-yellow gas, combining directly with nearly all elements. At 10°C one volume of water dissolves 3.10 volumes of chlorine, at 30°C only 1.77 volumes. Chlorine is widely used in making many everyday products. It is used for producing safe drinking water the world over. Even the smallest water supplies are now usually chlorinated. It is also extensively used in the production of paper products, dyestuffs, textiles, petroleum products, medicines, antiseptics, insecticides, foodstuffs, solvents, paints, plastics, and many other consumer products. Most of the chlorine produced is used in the manufacture of chlorinated compounds for sanitation, pulp bleaching, disinfectants, and textile processing. Further use is in the manufacture of chlorates, chloroform, carbon tetrachloride, and in

the extraction of bromine. Organic chemistry demands much from chlorine, both as an oxidizing agent and in substitution, since it often brings desired properties in an organic compound when substituted for hydrogen, as in one form of synthetic rubber. Chlorine is a respiratory irritant. The gas irritates the mucous membranes and the liquid burns the skin. As little as 3.5 ppm can be detected as an odor, and 1000 ppm is likely to be fatal after a few deep breaths. It was used as a war gas in 1915. Natural chlorine contains two isotopes, ^{35}Cl and ^{37}Cl .

Chromium — (*Gr. chroma*, color), Cr. Discovered in 1797 by Vauquelin, who prepared the metal the next year, chromium is a steel-gray, lustrous, hard metal that takes a high polish. The principal ore is *chromite* (FeCr_2O_4), which is found in Zimbabwe, Russia, South Africa, Turkey, Iran, Albania, Finland, Madagascar, the Philippines, and elsewhere. The U.S. has no appreciable chromite ore reserves. The metal is usually produced by reducing the oxide with aluminum. Chromium is used to harden steel, to manufacture stainless steel, and to form many useful alloys. Much is used in plating to produce a hard, beautiful surface and to prevent corrosion. Chromium is used to give glass an emerald green color. It finds wide use as a catalyst. All compounds of chromium are colored; the most important are the chromates of sodium and potassium (K_2CrO_4) and the dichromates ($\text{K}_2\text{Cr}_2\text{O}_7$) and the potassium and ammonium chrome alums, as $\text{KCr}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$. The dichromates are used as oxidizing agents in quantitative analysis, also in tanning leather. Other compounds are of industrial value; lead chromate is chrome yellow, a valued pigment. Chromium compounds are used in the textile industry as mordants, and by the aircraft and other industries for anodizing aluminum. The refractory industry has found chromite useful for forming bricks and shapes, as it has a high-melting point, moderate thermal expansion, and stability of crystalline structure. Chromium is an essential trace element for human health. Many chromium compounds, however, are acutely or chronically toxic, and some are carcinogenic. They should be handled with proper safeguards.

Cobalt — (*Kobald*, from the German, goblin or evil spirit, *cobaltos*, Greek, mine), Co. Discovered by Brandt about 1735. Cobalt occurs in the mineral *cobaltite*, *smaltite*, and *erythrite*, and is often associated with nickel, silver, lead, copper, and iron ores, from which it is most frequently obtained as a by-product. It is also present in meteorites. Important ore deposits are found in Congo-Kinshasa, Australia, Zambia, Russia, Canada, and elsewhere. The U.S. Geological Survey has announced that the bottom of the north central Pacific Ocean may have cobalt-rich deposits at relatively shallow depths in waters close to the Hawaiian Islands and other U.S. Pacific territories. Cobalt is a brittle, hard metal, closely resembling iron and nickel in appearance. It has a magnetic permeability of about two thirds that of iron. Cobalt tends to exist as a mixture of two allotropes over a wide temperature range; the β -form predominates below 400°C , and the α above that temperature. The transformation is sluggish and accounts in part for the wide variation in reported data on physical properties of cobalt. It is alloyed with iron, nickel and other metals to make Alnico, an alloy of unusual magnetic strength with many important

uses. Stellite alloys, containing cobalt, chromium, and tungsten, are used for high-speed, heavy-duty, high-temperature cutting tools, and for dies. Cobalt is also used in other magnet steels and stainless steels, and in alloys used in jet turbines and gas turbine generators. The metal is used in electroplating because of its appearance, hardness, and resistance to oxidation. The salts have been used for centuries for the production of brilliant and permanent blue colors in porcelain, glass, pottery, tiles, and enamels. It is the principal ingredient in Sevre's and Thenard's blue. A solution of the chloride ($\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$) is used as sympathetic ink. The cobalt amines are of interest; the oxide and the nitrate are important. Cobalt carefully used in the form of the chloride, sulfate, acetate, or nitrate has been found effective in correcting a certain mineral deficiency disease in animals. Soils should contain 0.13 to 0.30 ppm of cobalt for proper animal nutrition. Cobalt is found in Vitamin B-12, which is essential for human nutrition. Cobalt-60, an artificial isotope, is an important gamma ray source, and is extensively used as a tracer and a radiotherapeutic agent.

Copernicium — (After the astronomer Nicolaus Copernicus), Cn. In late February 1996, Sigurd Hofmann and his collaborators at GSI Darmstadt announced their discovery of Element-112, having 112 protons and 165 neutrons, with an atomic mass of 277. This element was made by bombarding a lead target with high-energy zinc ions. A single nucleus of Element-112 was detected, which was identified by its decay pattern. Evidence indicates that nuclei with 162 neutrons are held together more strongly than nuclei with a smaller or larger number of neutrons. This suggests a narrow "peninsula" of relatively stable isotopes around Element-114. In 2010 IUPAC approved the name and symbol Copernicium, Cn, for Element-112. Theoretical calculations and limited experimental measurements suggest that copernicium will have properties similar to mercury, possibly existing as a gas at ambient temperature.

Copper — (*L. cuprum*, from the island of Cyprus), Cu. The discovery of copper dates from prehistoric times. It is said to have been mined for more than 5000 years. It is one of man's most important metals. Copper is reddish colored, takes on a bright metallic luster, and is malleable, ductile, and a good conductor of heat and electricity (second only to silver in electrical conductivity). The electrical industry is one of the greatest users of copper. Copper occasionally occurs native, and is found in many minerals such as *cuprite*, *malachite*, *azurite*, *chalcocopyrite*, and *bornite*. Large copper ore deposits are found in the U.S., Chile, Zambia, Zaire, Peru, and Canada. The most important copper ores are the sulfides, oxides, and carbonates. From these, copper is obtained by smelting, leaching, and by electrolysis. Its alloys, brass and bronze, long used, are still very important; all American coins are now copper alloys; monel and gun metals also contain copper. The most important compounds are the oxide and the sulfate, blue vitriol; the latter has wide use as an agricultural poison and as an algicide in water purification. Copper compounds such as Fehling's solution are widely used in analytical chemistry in tests for sugar. High-purity copper (99.999 + %) is readily available commercially.

Curium — (Pierre and Marie Curie), Cm. Although curium follows americium in the periodic system, it was actually known before americium and was the third transuranium element to be discovered. It was identified by Seaborg, James, Morgan, and Ghiorso in 1944 at the wartime Metallurgical Laboratory in Chicago as a result of helium-ion bombardment of ^{239}Pu in the Berkeley, California, 60-inch cyclotron. Visible amounts (30 μg) of ^{242}Cm , in the form of the hydroxide, were first isolated by Werner and Perlman of the University of California in 1947. In 1950, Crane, Wallmann, and Cunningham found that the magnetic susceptibility of microgram samples of CmF_3 was of the same magnitude as that of GdF_3 . This provided direct experimental evidence for assigning an electronic configuration to Cm^{+3} . In 1951, the same workers prepared curium in its elemental form for the first time. Sixteen isotopes of curium are now known. The most stable, ^{247}Cm , with a half-life of 16 million years, is so short compared to the Earth's age that any primordial curium must have disappeared long ago from the natural scene. Minute amounts of curium probably exist in natural deposits of uranium, as a result of a sequence of neutron captures and β decays sustained by the very low flux of neutrons naturally present in uranium ores. ^{242}Cm and ^{244}Cm are available in multigram quantities. ^{248}Cm has been produced only in milligram amounts. Curium is similar in some regards to gadolinium, its rare-earth homolog, but it has a more complex crystal structure. Curium is silver in color, is chemically reactive, and is more electropositive than aluminum. CmO_2 , Cm_2O_3 , CmF_3 , CmF_4 , CmCl_3 , CmBr_3 , and CmI_3 have been prepared. Most compounds of trivalent curium are faintly yellow in color. ^{242}Cm generates about three watts of thermal energy per gram. This compares to one-half watt per gram of ^{238}Pu . This suggests use for curium as a power source. Curium absorbed into the body accumulates in the bones, and is therefore very toxic as its radiation destroys the red-cell forming mechanism. The maximum permissible total body burden of ^{244}Cm (soluble) in a human being is 0.3 μCi .

Darmstadtium — (Darmstadt, city in Germany), Ds. In 1987 Oganessian et al., at Dubna, claimed discovery of this element. Their experiments indicated the spontaneous fissioning nuclide $^{271}110$ with a half-life of 10 ms. More recently a group led by Armbruster at G.S.I. in Darmstadt, Germany, reported evidence of $^{269}110$, which was produced by bombarding lead for many days with more than 10^{18} nickel atoms. A detector searched each collision for Element 110's distinct decay sequence. On November 9, 1994, evidence of 110 was detected. In 2003 IUPAC approved the name darmstadtium, symbol Ds, for Element 110.

Dubnium — (named after the Joint Institute of Nuclear Research in Dubna, Russia). Db. In 1967 G. N. Flerov reported that a Soviet team working at Dubna may have produced a few atoms of $^{260}105$ and $^{261}105$ by bombarding ^{243}Am with ^{22}Ne . Later, it was reported that Dubna scientists synthesized Element 105 and determined its decay pattern and chemical properties. In April 1970, it was announced that Ghiorso, Nurmia, Harris, K. A. Y. Eskola, and P. L. Eskola, working at the University of California at Berkeley, had positively identified Element 105. When a ^{15}N nucleus is absorbed by a ^{249}Cf nucleus,

four neutrons are emitted and a new atom of $^{260}105$ with a half-life of 1.6 s is formed. Soon after the discovery the names Hahnium and Joliotium, named after Otto Hahn and Jean-Frederic Joliot and Mme. Joliot-Curie, were suggested as names for Element 105. The name Hahnium was used in the literature for several years, leading to considerable confusion. The IUPAC in August 1997 finally resolved the issue, naming Element 105 Dubnium with the symbol Db. Dubnium is thought to have properties similar to tantalum.

Dysprosium — (Gr. *dysprositos*, hard to get at), Dy. Dysprosium was discovered in 1886 by Lecoq de Boisbaudran, but not isolated. Neither the oxide nor the metal was available in relatively pure form until the development of ion-exchange separation and metallographic reduction techniques by Spedding and associates about 1950. Dysprosium occurs along with other so-called rare-earth or lanthanide elements in a variety of minerals such as *xenotime*, *fergusonite*, *gadolinite*, *euxenite*, *polycrase*, and *blomstrandite*. The most important sources, however, are from *monazite* and *bastnasite*. Dysprosium can be prepared by reduction of the trifluoride with calcium. The element has a metallic, bright silver luster. It is relatively stable in air at room temperature, and is readily attacked and dissolved, with the evolution of hydrogen, by dilute and concentrated mineral acids. The metal is soft enough to be cut with a knife and can be machined without sparking if overheating is avoided. Small amounts of impurities can greatly affect its physical properties. While dysprosium has not yet found many applications, its thermal neutron absorption cross section and high-melting point suggest metallurgical uses in nuclear control applications and for alloying with special stainless steels. A dysprosium oxide-nickel cermet has found use in cooling nuclear reactor rods. This cermet absorbs neutrons readily without swelling or contracting under prolonged neutron bombardment. In combination with vanadium, dysprosium has been used in making laser materials. Dysprosium-cadmium chalcogenides, as sources of infrared radiation, have been used for studying chemical reactions.

Einsteinium — (Albert Einstein [1879–1955]), Es. Einsteinium, the seventh transuranic element of the actinide series to be discovered, was identified by Ghiorso and co-workers at Berkeley in December 1952 in debris from the first large thermonuclear explosion, which took place in the Pacific in November 1952. The isotope produced was the 20-day ^{253}Es isotope. In 1961, a sufficient amount of einsteinium was produced to permit separation of a macroscopic amount of ^{253}Es . This sample weighed about 0.01 μg . A special magnetic-type balance was used in making this determination. ^{253}Es so produced was used to produce mendelevium. About 3 μg of einsteinium has been produced at Oak Ridge National Laboratories by irradiating for several years kilogram quantities of ^{239}Pu in a reactor to produce ^{242}Pu . This was then fabricated into pellets of plutonium oxide and aluminum powder, and loaded into target rods for an initial 1-year irradiation at the Savannah River Plant, followed by irradiation in a HFIR (High Flux Isotopic Reactor). After 4 months in the HFIR the targets were removed for chemical separation of the einsteinium from californium. Twenty-one isotopes and isomers of

einsteinium are now recognized. ^{254}Es has the longest half-life (276 days). Tracer studies using ^{253}Es show that einsteinium has chemical properties typical of a heavy trivalent, actinide element. Einsteinium is extremely radioactive. Great care must be taken when handling it.

Erbium — (*Ytterby*, a town in Sweden), Er. Erbium, one of the rare-earth elements of the lanthanide series, is found in the minerals mentioned under dysprosium above. In 1842 Mosander separated “yttria,” found in the mineral *gadolinite*, into three fractions which he called *yttria*, *erbia*, and *terbia*. The names *erbia* and *terbia* became confused in this early period. After 1860, Mosander’s *terbia* was known as *erbia*, and after 1877, the earlier known *erbia* became *terbia*. The *erbia* of this period was later shown to consist of five oxides, now known as *erbia*, *scandia*, *holmia*, *thulia* and *ytterbia*. By 1905 Urbain and James independently succeeded in isolating fairly pure Er_2O_3 . Klemm and Bommer first produced reasonably pure erbium metal in 1934 by reducing the anhydrous chloride with potassium vapor. The pure metal is soft and malleable and has a bright, silvery, metallic luster. As with other rare-earth metals, its properties depend to a certain extent on the impurities present. The metal is fairly stable in air and does not oxidize as rapidly as some of the other rare-earth metals. Recent production techniques, using ion-exchange reactions, have resulted in much lower prices of the rare-earth metals and their compounds. Erbium is finding nuclear and metallurgical uses. Added to vanadium, for example, erbium lowers the hardness and improves workability. Most of the rare-earth oxides have sharp absorption bands in the visible, ultraviolet, and near infrared. This property, associated with the electronic structure, gives beautiful pastel colors to many of the rare-earth salts. Erbium oxide gives a pink color and has been used as a colorant in glasses and porcelain enamel glazes.

Europium — (Europe), Eu. In 1890 Boisbaudran obtained basic fractions from samarium-gadolinium concentrates that had spark spectral lines not accounted for by samarium or gadolinium. These lines subsequently were shown to belong to europium. The discovery of europium is generally credited to Demarcay, who separated the rare earth in reasonably pure form in 1901. The pure metal was not isolated until much later. Europium is now prepared by mixing Eu_2O_3 with a 10% excess of lanthanum metal and heating the mixture in a tantalum crucible under high vacuum. The element is collected as a silvery-white metallic deposit on the walls of the crucible. As with other rare-earth metals, except for lanthanum, europium ignites in air at about 150 to 180 °C. Europium is about as hard as lead and is quite ductile. It is the most reactive of the rare-earth metals, quickly oxidizing in air. It resembles calcium in its reaction with water. *Bastnasite* and *monazite* are the principal ores containing europium. Europium has been identified spectroscopically in the sun and certain stars. Europium isotopes are good neutron absorbers and are being studied for use in nuclear control applications. Europium oxide is now widely used as a phosphor activator and europium-activated yttrium vanadate is in commercial use as the red phosphor in color TV tubes. Europium-doped plastic has been used as a laser material. Europium is one of the rarest and most costly of

the rare-earth metals, but with the development of ion-exchange techniques and special processes, the cost of the metal has been greatly reduced in recent years

Fermium — (Enrico Fermi [1901–1954], nuclear physicist), Fm. Fermium, the eighth transuranium element of the actinide series to be discovered, was identified by Ghiorso and co-workers in 1952 in the debris from a thermonuclear explosion in the Pacific in work involving the University of California Radiation Laboratory, the Argonne National Laboratory, and the Los Alamos Scientific Laboratory. The isotope produced was the 20-hour ^{255}Fm . During 1953 and early 1954, while discovery of elements 99 and 100 was withheld from publication for security reasons, a group from the Nobel Institute of Physics in Stockholm bombarded ^{238}U with ^{16}O ions, and isolated a 30-min α -emitter, which they ascribed to ^{250}Fm , without claiming discovery of the element. This isotope has since been identified positively, and the 30-min half-life confirmed. The chemical properties of fermium have been studied solely with tracer amounts, and in normal aqueous media only the (III) oxidation state appears to exist. The isotope ^{254}Fm and heavier isotopes can be produced by intense neutron irradiation of lower elements such as plutonium by a process of successive neutron capture interspersed with beta decays until these mass numbers and atomic numbers are reached. Twenty-two isotopes and isomers of fermium are known to exist. ^{257}Fm , with a half-life of 100.5 days, is the longest lived. ^{250}Fm , with a half-life of 28 min, has been shown to be a product of decay of ^{254}No . It was by chemical identification of ^{250}Fm that production of nobelium was confirmed. Fermium would probably have chemical properties resembling erbium.

Flerovium — (After the *Flerov* Laboratory of Nuclear Reactions, Russia), Fl. Although the synthesis of Element-114 was first reported in 1998 by a team at the Joint Institute for Nuclear Research (JINR) in Dubna, Russia, further experiments led to confusion, until the discovery was finally confirmed by groups in the U.S. and Germany in 2009-2011. IUPAC approved the name Flerovium in 2011. The most stable isotope so far discovered in ^{285}Fl , with a half-life of 0.13 s. Based on its electronic structure, flerovium is predicted to be a dense, volatile metal, possibly a gas at room temperature. It is calculated to be similar to lead in its chemistry, but probably less reactive.

Fluorine — (L. and F. *fluere*, flow, or flux), F. In 1529, Georgius Agricola described the use of fluorspar as a flux, and as early as 1670 Schwandhard found that glass was etched when exposed to fluorspar treated with acid. Scheele and many later investigators, including Davy, Gay-Lussac, Lavoisier, and Thenard, experimented with hydrofluoric acid, some experiments ending in tragedy. The element was finally isolated in 1886 by Moisson after nearly 74 years of continuous effort. Fluorine occurs chiefly in *fluorspar* (CaF_2) and *cryolite* (Na_2AlF_6), and is in *topaz* and other minerals. It is a member of the halogen family of elements, and is obtained by electrolyzing a solution of potassium hydrogen fluoride in anhydrous hydrogen fluoride in a vessel of metal or transparent fluorspar. Modern commercial production methods are essentially variations on the procedures first used by Moisson. Fluorine is the most electronegative and reactive of all elements. It is a pale yellow, corrosive gas, which reacts

with practically all organic and inorganic substances. Finely divided metals, glass, ceramics, carbon, and even water burn in fluorine with a bright flame. Until World War II, there was no commercial production of elemental fluorine. The atomic bomb project and nuclear energy applications, however, made it necessary to produce large quantities. Safe handling techniques have now been developed and it is possible at present to transport liquid fluorine by the ton. Fluorine and its compounds are used in producing enriched uranium (from the hexafluoride) and more than 100 commercial fluorochemicals, including many well-known high-temperature plastics. Hydrofluoric acid is extensively used for etching the glass of light bulbs, etc. Fluorochlorohydrocarbons were extensively used in air conditioning and refrigeration systems, but these compounds have been replaced fluorohydrocarbons to reduce the depletion of stratospheric ozone. The presence of fluorine as a soluble fluoride in drinking water to the extent of 2 ppm may cause mottled enamel in teeth, when used by children acquiring permanent teeth; in smaller amounts, however, fluorides are beneficial and are used in water supplies to prevent dental cavities. Elemental fluorine is used as an oxidizer in rocket engines. A number of fluorides of the rare gases xenon, radon, and krypton have been prepared. Elemental fluorine and the fluoride ion are highly toxic. The free element has a characteristic pungent odor, detectable in concentrations as low as 20 ppb, which is below the safe working level.

Francium — (France), Fr. Discovered in 1939 by Mlle. Marguerite Perey of the Curie Institute, Paris. Francium, the heaviest known member of the alkali metal series, occurs from alpha disintegration of actinium. It can also be made artificially by bombarding thorium with protons. While it occurs naturally in uranium minerals, there is probably less than 30 g of francium at any time in the total crust of the earth. It has the highest equivalent weight of any element, and is the most unstable of the first 101 elements of the periodic system. Forty-six isotopes and isomers of francium are recognized. The longest lived, ^{223}Fr , a daughter of ^{227}Ac , has a half-life of 22 min. This is the only isotope of francium occurring in nature. Because all known isotopes are highly unstable, knowledge of the chemical properties of this element comes from radiochemical techniques. No weighable quantity of the element has been prepared or isolated. The chemical properties of francium should most closely resemble cesium, and francium salts are found to coprecipitate with cesium salts from aqueous solution. The predicted melting point is around 27 °C, so elemental francium might be either solid or liquid.

Gadolinium — (*gadolinite*, a mineral named for Gadolin, a Finnish chemist), Gd. Gadolinia, the oxide of gadolinium, was separated by Marignac in 1880, and Lecoq de Boisbaudran independently isolated the element from Mosander's "yttria" in 1886. The element was named for the mineral *gadolinite* from which this rare earth was originally obtained. Gadolinium is found in several other minerals, including *monazite* and *bastnasite*, which are of commercial importance. The element has been purified only in recent years. With the development of ion-exchange and solvent extraction techniques, the availability and price of gadolinium and

the other rare-earth metals have greatly improved. The metal can be prepared by the reduction of the anhydrous fluoride with metallic calcium. As with other related rare-earth metals, it is silvery white, has a metallic luster, and is malleable and ductile. At room temperature, gadolinium crystallizes in the hexagonal, close-packed α form. Upon heating to 1235 °C, α -gadolinium transforms into the β form, which has a body-centered cubic structure. The metal is relatively stable in dry air, but in moist air it tarnishes with the formation of a loosely adhering oxide film which splits off and exposes more surface to oxidation. The metal reacts slowly with water and is soluble in dilute acid. Gadolinium has the highest thermal neutron capture cross section of any known element (49,000 barns). Natural gadolinium is a mixture of seven isotopes. Two of these, ^{155}Gd and ^{157}Gd , have excellent capture characteristics, but they are present naturally in low concentrations. As a result, gadolinium has a very fast burnout rate and has limited use as a nuclear control rod material. It has been used in making gadolinium yttrium garnets, which have important electronic applications. Compounds of gadolinium are used in making phosphors for color TV tubes. The metal has unusual superconductive properties. As little as 1% gadolinium has been found to improve the workability and resistance of iron, chromium, and related alloys to high temperatures and oxidation. Gadolinium ethyl sulfate has extremely low noise characteristics and may find use in duplicating the performance of amplifiers, such as the maser. The metal is ferromagnetic. Gadolinium is unique for its high magnetic moment and for its special Curie temperature (above which ferromagnetism vanishes) lying just at room temperature. This suggests uses as a magnetic component that senses hot and cold.

Gallium — (L. *Gallia*, France), Ga. Predicted and described by Mendeleev as eka-aluminum, and discovered spectroscopically by Lecoq de Boisbaudran in 1875, who in the same year obtained the free metal by electrolysis of a solution of the hydroxide in KOH, Gallium is often found as a trace element in *diaspore*, *sphalerite*, *germanite*, *bauxite*, and *coal*. Some flue dusts from burning coal have been shown to contain as much as 1.5% gallium. It is the only metal, except for mercury, cesium, and rubidium, which can be liquid near room temperature; this makes possible its use in high-temperature thermometers. It has one of the longest liquid ranges of any metal and has a low vapor pressure even at high temperatures. There is a strong tendency for gallium to supercool below its freezing point. Therefore, seeding may be necessary to initiate solidification. Ultrapure gallium has a beautiful, silvery appearance, and the solid metal exhibits a conchoidal fracture similar to glass. The metal expands 3.1% on solidifying; therefore, it should not be stored in glass or metal containers, as they may break as the metal solidifies. Gallium wets glass or porcelain and forms a brilliant mirror when it is painted on glass. It is widely used in doping semiconductors and producing solid-state devices such as transistors. Gallium arsenide is capable of converting electricity directly into coherent light. High-purity gallium is attacked slowly only by mineral acids. Magnesium gallate containing divalent impurities such as Mn^{+2} is finding use in commercial

ultraviolet activated powder phosphors. Gallium nitride has been used to produce blue light-emitting diodes such as those used in CD and DVD readers. Gallium was the key ingredient in the detector for the Gallex Experiment in the 1990s. In this experiment, 30.3 tons of gallium in the form of a $\text{GaCl}_3\text{-HCl}$ solution was used to detect solar neutrinos. Gallium readily alloys with most metals, and has been used as a component in low-melting alloys. Its toxicity appears to be of a low order, but it should be handled with care until more data are forthcoming.

Germanium — (L. *Germania*, Germany), Ge. Predicted by Mendeleev in 1871 as eka-silicon, and discovered by Winkler in 1886. The metal is found in *argyrodite*, a sulfide of germanium and silver; in *germanite*, which contains 8% of the element; in zinc ores; in coal; and in other minerals. The element is frequently obtained commercially from flue dusts of smelters processing zinc ores, and has been recovered from the by-products of combustion of certain coals. Its presence in coal insures a large reserve of the element in the years to come. Germanium can be separated from other metals by fractional distillation of its volatile tetrachloride. The tetrachloride may then be hydrolyzed to give GeO_2 ; the dioxide can be reduced with hydrogen to give the metal. The element is a gray-white metalloid, and in its pure state is crystalline and brittle, retaining its luster in air at room temperature. It is a very important semiconductor material. Zone-refining techniques have led to production of crystalline germanium for semiconductor use with an impurity of only one part in 10^{10} . Doped with arsenic, gallium, or other elements, it is used in thousands of electronic applications. Its application in fiber optics and infrared optical systems now provides the largest use for germanium. Germanium is also finding many other applications including use as an alloying agent, as a phosphor in fluorescent lamps, and as a catalyst. Germanium and germanium oxide are transparent to the infrared and are used in infrared spectrometers and other optical equipment, including extremely sensitive infrared detectors. Germanium oxide's high index of refraction and dispersion make it useful as a component of glasses used in wide-angle camera lenses and microscope objectives. The field of organogermanium chemistry is becoming increasingly important. Certain germanium compounds have a low mammalian toxicity, but a marked activity against certain bacteria, which makes them of interest as chemotherapeutic agents.

Gold — (Sanskrit *Jval*; Anglo-Saxon *gold*), Au (L. *aurum*, gold). Known and highly valued from earliest times, gold is found in nature as the free metal and in tellurides; it is very widely distributed and is almost always associated with quartz or pyrite. It occurs in veins and alluvial deposits, and is often separated from rocks and other minerals by sluicing and panning operations. About 25% of the world's gold output comes from South Africa, and about two-thirds of the total U.S. production now comes from South Dakota and Nevada. The metal is recovered from its ores by cyaniding, amalgamating, and smelting processes. Refining is also frequently done by electrolysis. Gold occurs in sea water to the extent of 0.1 to 2 mg/ton, depending on the location where the sample is taken. As yet, no method has been found for recovering gold from sea water profitably. It is estimated that all the gold in the

world, so far refined, could be placed in a single cube 60 ft on a side. Of all the elements, gold in its pure state is undoubtedly the most beautiful. It is metallic, having a yellow color when in a mass, but when finely divided it may be black, ruby, or purple. The Purple of Cassius is a delicate test for auric gold. It is the most malleable and ductile metal; 1 oz. of gold can be beaten out to 300 ft². It is a soft metal and is usually alloyed to give it more strength. The specific gravity of gold has been found to vary considerably depending on temperature, how the metal is precipitated, and how it is cold-worked. Gold is a good conductor of heat and electricity, and is unaffected by air and most reagents. It is used in coinage and is a standard for monetary systems in many countries. It is also extensively used for jewelry, decoration, dental work, and for plating. It is used for coating certain space satellites, as it is a good reflector of infrared radiation and is inert. Gold, like other precious metals, is measured in troy weight; when alloyed with other metals, the term *carat* is used to express the amount of gold present, 24 carats being pure gold. For many years the value of gold was set by the U.S. at \$20.67/troy ounce; in 1934 this value was fixed by law at \$35.00/troy ounce, 9/10th fine. On March 17, 1968, because of a financial crisis, a two-tiered pricing system was established whereby gold was still used to settle international accounts at the old \$35.00/troy ounce price while the price of gold on the private market would be allowed to fluctuate. Since that time, the price of gold on the free market has fluctuated widely. The most common gold compounds are auric chloride (AuCl₃) and chlorauric acid (HAuCl₄), the latter being used in photography for toning the silver image. ¹⁹⁸Au, with a half-life of 2.7 days, is used for treating cancer and other diseases. Disodium aurothiomalate is administered intramuscularly as a treatment for arthritis. A mixture of one part nitric acid with three parts hydrochloric acid is called *aqua regia* (because it dissolved gold, the King of Metals). For many years the temperature assigned to the freezing point of gold was 1063.0 °C; this served as a calibration fixed point for the International Temperature Scales (ITS-27 and ITS-48) and the International Practical Temperature Scale (IPTS-48). In 1968, a new International Practical Temperature Scale (IPTS-68) was adopted, which required that the freezing point of gold be changed to 1064.43 °C. In 1990 a new International Temperature Scale (ITS-90) was adopted bringing the triple point of H₂O to 0.01 °C and the freezing point of gold to 1064.18 °C.

Hafnium — (*Hafnia*, Latin name for Copenhagen), Hf. Hafnium was thought to be present in various minerals and concentrations many years prior to its discovery in 1923, credited to D. Coster and G. von Hevesey. On the basis of the Bohr theory, the new element was expected to be associated with zirconium. It was finally identified in *zircon* from Norway, by means of x-ray spectroscopic analysis. It was named in honor of the city in which the discovery was made. Most zirconium minerals contain 1% to 5% hafnium. It was originally separated from zirconium by repeated recrystallization of the double ammonium or potassium fluorides by von Hevesey and Jantzen. Metallic hafnium was first prepared by van Arkel and deBoer by passing the vapor of the tetraiodide over a heated tungsten filament. Almost all

hafnium metal now produced is made by reducing the tetrachloride with magnesium or with sodium (Kroll Process). Hafnium is a ductile metal with a brilliant silver luster. Its properties are considerably influenced by the impurities of zirconium present. Of all the elements, zirconium and hafnium are two of the most difficult to separate. Their chemistry is almost identical; however, the density of zirconium is about half that of hafnium. Very pure hafnium has been produced, with zirconium being the major impurity. Because hafnium has a good absorption cross section for thermal neutrons (almost 600 times that of zirconium), has excellent mechanical properties, and is extremely corrosion resistant, it is used for reactor control rods. Hafnium has been successfully alloyed with iron, titanium, niobium, tantalum, and other metals. Hafnium carbide is the most refractory binary composition known, and the nitride is the most refractory of all known metal nitrides (mp 3310 °C). Hafnium is used in gas-filled and incandescent lamps, and is an efficient “getter” for scavenging oxygen and nitrogen. Finely divided hafnium is pyrophoric and can ignite spontaneously in air. Care should be taken when machining the metal or when handling hot sponge hafnium. At 700 °C hafnium rapidly absorbs hydrogen to form the composition HfH_{1.86}. Hafnium is resistant to concentrated alkalis, but at elevated temperatures reacts with oxygen, nitrogen, carbon, boron, sulfur, and silicon. Halogens react directly to form tetrahalides.

Hassium — (named for the German state, Hesse) Hs. This element was first synthesized and identified in 1964 by the same G.S.I. Darmstadt Group who first identified *Bohrium* and *Meitnerium*. Presumably this element has chemical properties similar to osmium. Isotope ²⁶⁵108 was produced using a beam of ⁵⁸Fe projectiles, produced by the Universal Linear Accelerator (UNILAC) to bombard a ²⁰⁸Pb target. Discovery of *Bohrium* and *Meitnerium* was made using detection of isotopes with odd proton and neutron numbers. Elements having even atomic numbers have been thought to be less stable against spontaneous fusion than odd elements. The production of ²⁶⁵108 in the same reaction as was used at G.S.I. was confirmed at Dubna with detection of the seventh member of the decay chain ²⁵³Es. Isotopes of *Hassium* are believed to decay by spontaneous fission, explaining why 109 was produced before 108. IUPAC adopted the name *Hassium* after the German state of Hesse in September 1997. In June 2001 it was announced that hassium is the heaviest element to have its chemical properties analyzed. A research team at the UNILAC heavy-ion accelerator in Darmstadt, Germany built an instrument to detect and analyze hassium. Atoms of curium-248 were collided with atoms of magnesium-26, producing about 6 atoms of hassium with a half-life of 9 s. This was sufficiently long to obtain data showing that hassium atoms react with oxygen to form hassium oxide molecules. These condensed at a temperature consistent with the behavior of Group 8 elements. This experiment appears to confirm hassium’s location under osmium in the periodic table.

Helium — (Gr. *helios*, the sun), He. Evidence of the existence of helium was first obtained by Janssen during the solar eclipse of 1868 when he detected a new line in the solar spectrum; Lockyer and Frankland suggested the name

helium for the new element; in 1895, Ramsay discovered helium in the uranium mineral *cleveite*, and it was independently discovered in *cleveite* by the Swedish chemists Cleve and Langlet about the same time. Rutherford and Roys in 1907 demonstrated that α particles are helium nuclei. Except for hydrogen, helium is the most abundant element found throughout the universe. Helium is extracted from natural gas; all natural gas contains at least trace quantities of helium. It has been detected spectroscopically in great abundance, especially in the hotter stars, and it is an important component in both the proton-proton reaction and the carbon cycle, which account for the energy of the sun and stars. The fusion of hydrogen into helium provides the energy of the hydrogen bomb. The helium content of the atmosphere is about 1 part in 200,000. It is present in various radioactive minerals as a decay product. Much of the world's supply of helium is obtained from wells in Texas, Colorado, and Kansas. Helium has the lowest triple-point temperature of any element and has found wide use in cryogenic research, as its boiling point is near 4 K. Its use in the study of superconductivity is vital. Liquid helium (^4He) exists in two forms: He^{I} and He^{II} , with a sharp transition point at 2.174 K (3.83 cm Hg). $^4\text{He}^{\text{I}}$ (above this temperature) is a normal liquid, but $^4\text{He}^{\text{II}}$ (below it) is unlike any other known substance. It expands on cooling; its conductivity for heat is enormous; and neither its heat conduction nor viscosity obeys normal rules. It has other peculiar properties. Helium is the only liquid that cannot be solidified by lowering the temperature at atmospheric pressure. It remains liquid down to absolute zero at ordinary pressures, but it can readily be solidified by increasing the pressure. Solid ^3He and ^4He are unusual in that both can readily be changed in volume by more than 30% by application of pressure. The specific heat of helium gas is unusually high. The density of helium vapor at the normal boiling point is also very high, with the vapor expanding greatly when heated to room temperature. Containers filled with helium gas at 5 to 10 K should be treated as though they contained liquid helium due to the large increase in pressure resulting from warming the gas to room temperature. While helium normally has a 0 valence, it seems to have a weak tendency to combine with certain other elements. Means of preparing helium difluoride have been studied, and species such as HeNe and the molecular ions He^+ and He^{++} have been investigated. Helium is widely used as an inert gas shield for arc welding; as a protective gas in growing silicon and germanium crystals, and in titanium and zirconium production; as a cooling medium for nuclear reactors, and as a gas for supersonic wind tunnels. A mixture of helium and oxygen is used as an artificial atmosphere for divers and others working under pressure. Different ratios of He/O_2 are used for different depths at which the diver is operating. Helium is extensively used for filling balloons as it is a much safer gas than hydrogen. One of the recent largest uses for helium has been for pressurizing liquid fuel rockets. A Saturn booster such as used on the Apollo lunar missions required about 13 million ft^3 of helium for a firing, plus more for checkouts. Liquid helium's use in magnetic resonance imaging (MRI) continues to increase as the use of this diagnostic technique expands. Lifting gas applications are increasing. Various

companies in addition to Goodyear, are now using "blimps" for advertising. The Navy and the Air Force are investigating the use of airships to provide early warning systems to detect low-flying cruise missiles. NASA is currently using helium-filled balloons to sample the atmosphere in Antarctica to study holes in the ozone layer. Research on and development of materials which become superconductive at temperatures well above the boiling point of helium could have a major impact on the demand for helium. Less costly refrigerants having boiling points considerably higher could replace the present need to cool such superconductive materials to the boiling point of helium.

Holmium — (L. *Holmia*, for Stockholm), Ho. The spectral absorption bands of holmium were noticed in 1878 by the Swiss chemists Delafontaine and Soret, who announced the existence of an "Element X." Cleve, of Sweden, later independently discovered the element while working on erbia earth. The element is named after Cleve's native city. Pure holmium, the yellow oxide, was prepared by Homborg in 1911. Holmium occurs in *gadolinite*, *monazite*, and in other rare-earth minerals. It is commercially obtained from monazite, occurring in that mineral to the extent of about 0.05%. It has been isolated by the reduction of its anhydrous chloride or fluoride with calcium metal. Pure holmium has a metallic to bright silver luster. It is relatively soft and malleable, and is stable in dry air at room temperature, but rapidly oxidizes in moist air and at elevated temperatures. Its high magnetic permeability leads to applications in high-field magnets. It is also used in near-infrared lasers.

Hydrogen — (Gr. *hydro*, water, and *genes*, forming), H. Hydrogen was prepared many years before it was recognized as a distinct substance by Cavendish in 1766. It was named by Lavoisier. Hydrogen is the most abundant of all elements in the universe, and it is thought that the heavier elements were, and still are, being built from hydrogen and helium. It has been estimated that hydrogen makes up more than 90% of all the atoms or three-quarters of the mass of the universe. It is found in the sun and most stars, and plays an important part in the proton-proton reaction and carbon-nitrogen cycle, which accounts for the energy of the sun and stars. It is thought that hydrogen is a major component of the planet Jupiter and that at some depth in the planet's interior the pressure is so great that solid molecular hydrogen is converted into solid metallic hydrogen. On Earth, hydrogen occurs chiefly in combination with oxygen in water, but it is also present in organic matter such as living plants, petroleum, coal, etc. It is present as the free element in the atmosphere, but only to the extent of less than 1 ppm by volume. It is the lightest of all gases, and combines with other elements, sometimes explosively, to form compounds. Great quantities of hydrogen are required commercially for the fixation of nitrogen from the air in the Haber ammonia process and for the hydrogenation of fats and oils. It is also used in large quantities in methanol production, in hydrodealkylation, hydrocracking, and hydrodesulfurization. It is also used as a rocket fuel, for cutting and welding of metals, for production of hydrochloric acid, for the reduction of metallic ores, and for filling balloons. The

lifting power of 1 ft³ of hydrogen gas is about 0.076 lb at 0 °C, 760 mm pressure. Production of hydrogen in the U.S. alone amounts to about 3 billion cubic feet per year. It is prepared by the action of steam on heated carbon, by decomposition of certain hydrocarbons with heat, by the electrolysis of water, or by the displacement from acids by certain metals. It is also produced by the action of sodium or potassium hydroxide on aluminum. Liquid hydrogen is important in cryogenics and in the study of superconductivity, as its melting point is only about 20 K. Hydrogen consists of three isotopes, most of which is ¹H. In 1932, Urey announced the discovery of a stable isotope, deuterium (²H or D). Deuterium is present in natural hydrogen to the extent of about 0.01%. Two years later an unstable isotope, tritium (³H), was discovered. Tritium has a half-life of about 12.31 years. Tritium atoms are also present in natural hydrogen but in a much smaller proportion. Tritium is readily produced in nuclear reactors and is used in the production of the hydrogen bomb. It is also used as a radioactive agent in making luminous paints, and as a tracer. Heavy water, deuterium oxide (D₂O), is used as a moderator to slow down neutrons. Hydrogen gas under ordinary conditions is a mixture of two kinds of molecules, known as *ortho*- and *para*-hydrogen, which differ from one another by the spins of their electrons and nuclei. Normal hydrogen at room temperature contains 25% of the *para* form and 75% of the *ortho* form. The *ortho* form cannot be prepared in the pure state. Since the two forms differ in energy, the physical properties also differ. The melting and boiling points of *parahydrogen* are about 0.1 °C lower than those of normal hydrogen. Both stationary and mobile power sources using hydrogen combustion offer a major advantage for reducing atmospheric carbon dioxide and retarding global temperature rise. The “hydrogen economy” is expected to grow rapidly as steps are taken to reduce the combustion of fossil fuels.

Indium — (from the brilliant indigo line in its spectrum), In. Discovered spectroscopically in 1863 by Reich and Richter, who later isolated the metal. Indium is most frequently associated with zinc materials, and it is from these that most commercial indium is now obtained; however, it is also found in iron, lead, and copper ores. Until 1924, a gram or so constituted the world's supply of this element in isolated form. It is probably about as abundant as silver. About 4 million troy ounces of indium are now produced annually, much of it from Canada. It is available in ultrapure form. Indium is a very soft, silvery-white metal with a brilliant luster. The pure metal gives a high-pitched “cry” when bent. In liquid form it wets glass, as does gallium. It has found application in making low-melting alloys; an alloy of 24% indium–76% gallium is liquid at room temperature. Indium is used in making bearing alloys, and in the form of various semiconductors (InSb, InAs, etc.) it has many applications in transistors, rectifiers, thermistors, liquid crystal displays, batteries, solar cells, and photoconductors. It can be plated onto metal and evaporated onto glass, forming a mirror as good as that made with silver but with more resistance to atmospheric corrosion. Indium has a low order of toxicity.

Iodine — (Gr. *iodes*, violet), I. Discovered by Courtois in 1811. Iodine, a halogen, occurs sparingly in the form of iodides in sea water from which it is assimilated by seaweeds, in Chilean saltpeter and nitrate-bearing earth, known as *caliche* in brines from old sea deposits, and in brackish waters from oil and salt wells. Ultrapure iodine can be obtained from the reaction of potassium iodide with copper sulfate. Several other methods of isolating the element are known. Iodine is a bluish-black, lustrous solid, volatilizing at ordinary temperatures into a blue-violet gas with an irritating odor; it forms compounds with many elements, but is less active than the other halogens, which displace it from iodides. Iodine exhibits some metallic-like properties. It dissolves readily in chloroform, carbon tetrachloride, or carbon disulfide to form beautiful purple solutions. It is only slightly soluble in water. Iodine compounds are important in organic chemistry and very useful in medicine. The artificial radioisotope ¹³¹I, with a half-life of 8 days, has been used in treating the thyroid gland. The most common compounds are the iodides of sodium and potassium (NaI and KI) and the iodates (KIO₃). Lack of iodine is the cause of goiter. Iodides and thyroxin, which contains iodine, are used internally in medicine, and a solution of KI and iodine in alcohol is used for external wounds. Potassium iodide finds use in photography. The deep blue color with starch solution is characteristic of the free element. Care should be taken in handling and using iodine, as contact with the skin can cause lesions; iodine vapor is intensely irritating to the eyes and mucous membranes.

Iridium — (L. *iris*, rainbow), Ir. Discovered in 1803 by Tennant in the residue left when crude platinum is dissolved by aqua regia. The name iridium is appropriate, for its salts are highly colored. Iridium, a metal of the platinum family, is white, similar to platinum, but with a slight yellowish cast. It is very hard and brittle, making it hard to machine, form, or work. It is the most corrosion-resistant metal known, and was used in making the original standard meter bar, which is a 90% platinum–10% iridium alloy. Iridium is not attacked by any of the acids nor by aqua regia, but is attacked by molten salts, such as NaCl and NaCN. Iridium occurs uncombined in nature with platinum and other metals of this family in alluvial deposits. It is recovered as a by-product from the nickel mining industry. The largest reserves and production of the platinum group of metals, which includes iridium, is in South Africa, followed by Russia and Canada. Meteorites contain small amounts of iridium. The presence of iridium has recently been used in examining the Cretaceous-Tertiary (K-T) boundary. Because iridium is found widely distributed at the K-T boundary, it has been suggested that a large meteorite or asteroid collided with the Earth, killing the dinosaurs, and creating a large dust cloud and crater. Searches for such a crater point to one in the Yucatan, known as Chicxulub. Iridium has found use in making crucibles and apparatus for use at high temperatures. It is also used for electrical contacts. Its principal use is as a hardening agent for platinum. With osmium, it forms an alloy that is used for tipping pens and compass bearings. The density of iridium is only slightly lower than that of osmium, which has been generally credited as being the heaviest

known element. Calculations of the densities of iridium and osmium from the space lattices give values of 22.65 and 22.61 g/cm³, respectively. These values may be more reliable than actual physical measurements. At present, therefore, we know that either iridium or osmium is the densest known element, but the data do not yet allow selection between the two.

Iron — (Anglo-Saxon, *iron*), Fe (*L. ferrum*). The use of iron is prehistoric. Genesis mentions that Tubal-Cain, seven generations from Adam, was “an instructor of every artificer in brass and iron.” A remarkable iron pillar, dating to about A.D. 400, remains standing today in Delhi, India. This solid shaft of wrought iron is about 7¼ m high by 40 cm in diameter. Corrosion to the pillar has been minimal although it has been exposed to the weather since its erection. Iron is a relatively abundant element in the universe. It is found in the sun and many types of stars in considerable quantity. It has been suggested that the iron we have here on Earth may have originated in a supernova. Iron is a very difficult element to produce in ordinary nuclear reactions, such as would take place in the sun. Iron is found native as a principal component of a class of iron–nickel meteorites known as *siderites*, and is a minor constituent of the other two classes of meteorites. The core of the Earth, 2150 miles in radius, is thought to be largely composed of iron with about 10% occluded hydrogen. The metal is the fourth most abundant element, by weight, making up the crust of the Earth. The most common ore is *hematite* (Fe₂O₃). *Magnetite* (Fe₃O₄) is frequently seen as *black sands* along beaches and banks of streams. *Lodestone* is another form of magnetite. *Taconite* is becoming increasingly important as a commercial ore. Iron is a vital constituent of plant and animal life, and appears in hemoglobin. It has a rich chemistry, both inorganic and organometallic. The pure metal is not often encountered in commerce, but is usually alloyed with carbon or other metals. The pure metal is very reactive chemically, and rapidly corrodes, especially in moist air or at elevated temperatures. It has four principal allotropic forms, known as α , γ , δ , and ϵ . The α - γ transition point is 912 °C; γ - δ is 1394 °C; and the ϵ phase appears at high pressures. The α form is magnetic, but the magnetism disappears above 771 °C, although the lattice remains unchanged. The relations of these forms are complex. Pig iron is an alloy containing about 3% carbon with varying amounts of S, Si, Mn, and P. It is hard, brittle, fairly fusible, and is used to produce other alloys, including steel. Wrought iron contains only a few tenths of a percent of carbon, is tough, malleable, less fusible, and usually has a “fibrous” structure. Carbon steel is an alloy of iron with carbon, with small amounts of Mn, S, P, and Si. Alloy steels are carbon steels with other additives such as nickel, chromium, vanadium, etc. Iron is the cheapest and most abundant, useful, and important of all metals.

Krypton — (Gr. *kryptos*, the hidden one), Kr. Discovered in 1898 by Ramsay and Travers in the residue left after liquid air had nearly boiled away, krypton is present in the air to the extent of about 1 ppm. The atmosphere of Mars has been found to contain 0.3 ppm of krypton. It is one of the noble gases. It is characterized by its brilliant green and orange spectral lines. The spectral lines of krypton

are easily produced and some are very sharp; at one time the meter was defined in terms of the wavelength of a krypton line. Solid krypton is a white crystalline substance with a face-centered cubic structure that is common to all the rare gases. While krypton was first thought of as a noble gas that does not combine with other elements, the existence of several krypton compounds has been established. Krypton difluoride has been prepared in gram quantities and can be made by several methods. ⁸⁵Kr has found application in chemical analysis. By imbedding the isotope in various solids, *kryptonates* are formed. The activity of these kryptonates is sensitive to chemical reactions at the surface. Estimates of the concentration of reactants are therefore made possible. Krypton is used in certain photographic flash lamps for high-speed photography.

Lanthanum — (Gr. *lanthanein*, to lie hidden), La. Mosander in 1839 extracted a new earth *lanthana*, from impure cerium nitrate, and recognized the new element. Lanthanum is found in rare-earth minerals such as *cerite*, *monazite*, *allanite*, and *bastnasite*. Monazite and bastnasite are principal ores in which lanthanum occurs in percentages up to 25% and 38%, respectively. Misch metal, used in making lighter flints, contains about 25% lanthanum. Lanthanum was first isolated in relatively pure form in 1923. Ion-exchange and solvent extraction techniques have led to much easier isolation of the rare-earth elements, resulting in improved availability. The metal can be produced by reducing the anhydrous fluoride with calcium. Lanthanum is silvery white, malleable, ductile, and soft enough to be cut with a knife. It is one of the most reactive of the rare-earth metals. It oxidizes rapidly when exposed to air. Cold water attacks lanthanum slowly, and hot water attacks it much more rapidly. The metal reacts directly with elemental carbon, nitrogen, boron, selenium, silicon, phosphorus, sulfur, and with halogens. At 310 °C, lanthanum changes from a hexagonal to a face-centered cubic structure, and at 865 °C it again transforms into a body-centered cubic structure. Rare-earth compounds containing lanthanum are extensively used in carbon lighting applications, especially by the motion picture industry for studio lighting and projection. This application consumes about 25% of the rare-earth compounds produced. La₂O₃ improves the alkali resistance of glass, and is used in making special optical glasses. Small amounts of lanthanum, as an additive, can be used to produce nodular cast iron. Hydrogen sponge alloys containing lanthanum can take up to 400 times their own volume of hydrogen gas, and thus may be useful in energy storage systems. Lanthanum and its compounds have a low to moderate acute toxicity rating; therefore, care should be taken in handling them.

Lawrencium — (Ernest O. Lawrence [1901–1958], inventor of the cyclotron), Lr. This member of the 5f transition elements (actinide series) was discovered in March 1961 by A. Ghiorso, T. Sikkeland, A. E. Larsh, and R. M. Latimer. A 3- μ g californium target, consisting of a mixture of isotopes of mass number 249, 250, 251, and 252, was bombarded with either ¹⁰B or ¹¹B. The electrically charged transmutation nuclei recoiled with an atmosphere of helium and were collected on a thin copper conveyor tape which was then moved to place the collected atoms

in front of a series of solid-state detectors. The isotope of element 103 produced in this way decayed by emitting an 8.6-MeV alpha particle with a half-life of 8 s. In 1967, Flerov and associates of the Dubna Laboratory reported their inability to detect an alpha emitter with a half-life of 8 s which was assigned by the Berkeley group to $^{257}\text{103}$. This assignment has been changed to ^{258}Lr or ^{259}Lr . In 1965, the Dubna workers found a longer-lived lawrencium isotope, ^{256}Lr , with a half-life of 35 s. In 1968, Ghiorso and associates at Berkeley were able to use a few atoms of this isotope to study the oxidation behavior of lawrencium. Using solvent extraction techniques and working very rapidly, they extracted lawrencium ions from a buffered aqueous solution into an organic solvent, completing each extraction in about 30 s. It was found that lawrencium behaves differently from dipositive nobelium and more like the tripositive elements earlier in the actinide series.

Lead — (Anglo-Saxon *lead*), Pb (L. *plumbum*). Long known, mentioned in Exodus. The alchemists believed lead to be the oldest metal and associated it with the planet Saturn. Native lead occurs in nature, but it is rare. Lead is obtained chiefly from *galena* (PbS) by a roasting process. *Anglesite* (PbSO_4), *cerussite* (PbCO_3), and *minim* (Pb_3O_4) are other common lead minerals. Lead is a bluish-white metal of bright luster, is very soft, highly malleable, ductile, and a poor conductor of electricity. It is very resistant to corrosion; lead pipes bearing the insignia of Roman emperors, used as drains from the baths, are still in service. It is used in containers for corrosive liquids (such as sulfuric acid) and may be toughened by the addition of a small percentage of antimony or other metals. Its alloys include solder, type metal, and various antifriction metals. Great quantities of lead, both as the metal and as the dioxide, are used in storage batteries. Lead is also used for cable covering, plumbing, and ammunition. The metal is very effective as a sound absorber, is used as a radiation shield around x-ray equipment and nuclear reactors, and is used to absorb vibration. Lead, alloyed with tin, is used in making organ pipes. White lead, the basic carbonate, sublimed white lead (PbSO_4), chrome yellow (PbCrO_4), red lead (Pb_3O_4), and other lead compounds are used extensively in paints, although in recent years the use of lead in paints has been drastically curtailed to eliminate or reduce health hazards. Lead oxide is used in producing fine "crystal glass" and "flint glass" of a high index of refraction for achromatic lenses. The nitrate and the acetate are soluble salts. Lead salts such as lead arsenate have been used as insecticides, but their use in recent years has been practically eliminated in favor of less harmful organic compounds. Care must be used in handling lead as it is a cumulative poison. Environmental concern with lead poisoning led to elimination of lead tetraethyl in gasoline. The U.S. Occupational Safety and Health Administration (OSHA) has recommended that industries limit airborne lead in the workplace to $50\ \mu\text{g}/\text{m}^3$.

Lithium — (Gr. *lithos*, stone), Li. Discovered by Arfvedson in 1817. Lithium is the lightest of all metals, with a density only about half that of water. It does not occur free in nature; combined it is found in small amounts in nearly all igneous rocks and in the waters of many mineral springs. *Lepidolite*, *spodumene*, *petalite*, and *amblygonite* are the more important minerals containing it.

Lithium is presently being recovered from brines of Searles Lake, in California, and from Nevada, Chile, and Argentina. Large deposits of spodumene are found in North Carolina. The metal is produced electrolytically from the fused chloride. Lithium is silvery in appearance, much like Na, K, and other members of the alkali metal series. It reacts with water, but not as vigorously as sodium. Lithium imparts a beautiful crimson color to a flame, but when the metal burns strongly the flame is a dazzling white. In recent years, the production of lithium metal and its compounds has increased greatly. Because the metal has the highest specific heat of any solid element, it has found use in heat transfer applications; however, it is corrosive and requires special handling. The metal has been used as an alloying agent, is of interest in synthesis of organic compounds, has important pharmaceutical uses, and has nuclear applications. It ranks as a leading contender as a battery anode material because it has a high electrochemical potential. Lithium is also used in special glasses and ceramics. Lithium chloride is one of the most hygroscopic materials known, and it, as well as lithium bromide, is used in air conditioning and industrial drying systems. Lithium stearate is used as an all-purpose and high-temperature lubricant. The use of lithium-ion storage batteries in applications ranging from cell phones to automobiles is growing rapidly.

Livermorium — (Lawrence *Livermore* National Laboratory), Lv. A single atom of Element-116 was first synthesized in 2000 at Lawrence Livermore Laboratory in collaboration with workers at JINR, Dubna. The name Livermorium was adopted by IUPAC in 2012. Livermorium falls at the top of the chalcogen group: oxygen, sulfur, selenium, tellurium, and polonium. No information is available on its physical and chemical properties. The most stable isotope, ^{293}Lv , has a half-life of 61 ms.

Lutetium — (Lutetia, ancient name for Paris, sometimes called *cassiopeium* in Germany), Lu. In 1907, Urbain described a process by which Marignac's ytterbium (1879) could be separated into the two elements, ytterbium (neoytterbium) and lutetium. These elements were identical with "aldebaranium" and "cassiopeium," independently discovered by von Weisbach about the same time. Charles James of the University of New Hampshire also independently prepared the very pure oxide, *lutecia*, at this time. The spelling of the element was changed from *lutecium* to *lutetium* in 1949. Lutetium occurs in very small amounts in nearly all minerals containing yttrium, and is present in *monazite*, which is a commercial source, to the extent of about 0.003%. The pure metal was only isolated later and is one of the most difficult to prepare. It can be prepared by the reduction of anhydrous LuCl_3 or LuF_3 by an alkali or alkaline earth metal. The metal is silvery white and relatively stable in air. While new techniques, including ion-exchange reactions, have been developed to separate the various rare-earth elements, lutetium is still the most costly of all rare earths. Stable lutetium isotopes, which emit pure beta radiation after thermal neutron activation, can be used as catalysts in cracking, alkylation, hydrogenation, and polymerization. Virtually no other commercial uses have been found. Lutetium, like other rare-earth metals, is thought to have a low toxicity rating.

Magnesium — (*Magnesia*, district in Thessaly), Mg. Compounds of magnesium have long been known. Black recognized magnesium as an element in 1755. It was isolated by Davy in 1808, and prepared in coherent form by Bussy in 1831. Magnesium is the eighth most abundant element in the Earth's crust. It does not occur uncombined, but is found in large deposits in the form of *magnesite*, *dolomite*, and other minerals. The metal is now principally obtained in the U.S. by electrolysis of fused magnesium chloride derived from brines, wells, and sea water. Magnesium is a light, silvery-white, and fairly tough metal. It tarnishes slightly in air, and finely divided magnesium readily ignites upon heating in air and burns with a dazzling white flame. It has been used in flashlight photography, flares, and pyrotechnics, including incendiary bombs. It is one third lighter than aluminum, and in alloys is essential for airplane and missile construction. The metal improves the mechanical, fabrication, and welding characteristics of aluminum when used as an alloying agent. Magnesium is used in producing nodular graphite in cast iron, and is used as an additive to conventional propellants. It is also used as a reducing agent in the production of pure uranium and other metals from their salts. The hydroxide (*milk of magnesia*), chloride, sulfate (*Epsom salts*), and citrate are used in medicine. Dead-burned magnesite is employed for refractory purposes such as brick and liners in furnaces and converters. Calcined magnesia is also used for water treatment and in the manufacture of rubber, paper, etc. Organic magnesium compounds (Grignard's reagents) are important. Magnesium is an important element in both plant and animal life. Chlorophylls are magnesium-centered porphyrins. The adult daily requirement of magnesium is about 300 mg/day, but this is affected by various factors. Great care should be taken in handling magnesium metal, especially in the finely divided state, as serious fires can occur. Water should not be used on burning magnesium or on magnesium fires.

Manganese — (*L. magnes*, magnet, from magnetic properties of pyrolusite; *It. manganese*, corrupt form of *magnesia*), Mn. Recognized by Scheele, Bergman, and others as an element and isolated by Gahn in 1774 by reduction of the dioxide with carbon. Manganese minerals are widely distributed; oxides, silicates, and carbonates are the most common. The discovery of large quantities of manganese nodules on the floor of the oceans holds promise as a source of manganese. These nodules contain about 24% manganese together with many other elements in lesser abundance. Most manganese today is obtained from ores found in Ukraine, Brazil, Australia, Republic of So. Africa, Gabon, China, and India. *Pyrolusite* (MnO_2) and *rhodochrosite* ($MnCO_3$) are among the most common manganese minerals. The metal is obtained by reduction of the oxide with sodium, magnesium, aluminum, or by electrolysis. It is gray-white, resembling iron, but is harder and very brittle. The metal is reactive chemically, and decomposes in cold water slowly. Manganese is used to form many important alloys. In steel, manganese improves the rolling and forging qualities, strength, toughness, stiffness, wear resistance, hardness, and hardenability. With aluminum and antimony, especially with small

amounts of copper, it forms highly ferromagnetic alloys. Manganese metal is ferromagnetic only after special treatment. The pure metal exists in four allotropic forms. The alpha form is stable up to 727 °C; gamma manganese, which is metastable at ordinary temperatures, is soft, easily cut, and capable of being bent. The dioxide (pyrolusite) is used as a depolarizer in dry cells, and is used to "decolorize" glass that is colored green by impurities of iron. Manganese by itself colors glass an amethyst color, and is responsible for the color of true amethyst. The dioxide is also used in the preparation of oxygen and chlorine, and in drying black paints. The permanganate is a powerful oxidizing agent and is used in quantitative analysis and in medicine. Manganese is widely distributed throughout the animal kingdom. It is an important trace element and may be essential for utilization of vitamin B₁₂.

Meitnerium — (Lise Meitner [1878–1968], Austrian–Swedish physicist and mathematician), Mt. In 1982, Element 109 was made and identified by physicists at the Heavy Ion Research Laboratory (G.S.I.), Darmstadt, Germany, by bombarding a target of ²⁰⁹Bi with accelerated nuclei of ⁵⁸Fe. In August 1997 IUPAC adopted the name meitnerium for this element, honoring Lise Meitner. The production of Mt has been extremely small. It took a week of target bombardment (10¹¹ nuclear encounters) to produce a single atom. Oganessian and his team at Dubna in 1984 repeated the Darmstadt experiment using a tenfold irradiation dose. One fission event from seven alpha decays of Mt was observed, thus indirectly confirming the existence of isotope ²⁶⁶Mt.

Mendelevium — (Dmitri Mendeleev [1834–1907]), Md. Mendelevium, the ninth transuranium element of the actinide series to be discovered, was first identified by Ghiorso, Harvey, Choppin, Thompson, and Seaborg early in 1955 as a result of the bombardment of the isotope ²⁵³Es with helium ions in the Berkeley 60-inch cyclotron. The isotope produced was ²⁵⁶Md, which has a half-life of 78 min. This first identification was notable in that ²⁵⁶Md was synthesized on a one-atom-at-a-time basis. ²⁵⁸Md has a half-life of 51.5 days. It now appears possible that eventually enough ²⁵⁸Md can be made so that some of its physical properties can be determined. ²⁵⁶Md has been used to elucidate some of the chemical properties of mendelevium in aqueous solution. Experiments seem to show that the element possesses a moderately stable dipositive (II) oxidation state in addition to the tripisitive (III) oxidation state, which is characteristic of actinide elements.

Mercury — (Planet *Mercury*), Hg (*hydrargyrum*, liquid silver). Known to ancient Chinese and Hindus; found in Egyptian tombs of 1500 B.C. Mercury is the only common metal liquid at ordinary temperatures. It only rarely occurs free in nature. The chief ore is *cinnabar* (HgS). Spain and China produce about 75% of the world's supply of the metal. The commercial unit for handling mercury is the "flask," which weighs 76 lb (34.46 kg). The metal is obtained by heating cinnabar in a current of air and by condensing the vapor. It is a heavy, silvery-white metal; a rather poor conductor of heat, as compared with other metals, and a fair conductor of electricity. It easily forms alloys with many metals, such as gold, silver, and tin, which are called *amalgams*. Its ease in

amalgamating with gold is made use of in the recovery of gold from its ores. The metal is widely used in laboratory work for making thermometers, barometers, diffusion pumps, and many other instruments. It is used in making mercury-vapor lamps and advertising signs, etc., and is used in mercury switches and other electrical apparatus. Other uses are in making pesticides, mercury cells for caustic soda and chlorine production, antifouling paint, batteries, and catalysts. The previously heavy use in dental preparations is being phased out because of toxicity concerns. The most important salts are mercuric chloride HgCl_2 (corrosive sublimate — a violent poison), mercurous chloride Hg_2Cl_2 (calomel, occasionally still used in medicine), mercury fulminate ($\text{Hg}(\text{ONC})_2$), a detonator widely used in explosives, and mercuric sulfide (HgS , vermilion, a high-grade paint pigment). Organic mercury compounds are important. It has been found that an electrical discharge causes mercury vapor to combine with neon, argon, krypton, and xenon. These products, held together with van der Waals' forces, correspond to HgNe , HgAr , HgKr , and HgXe . Mercury is a virulent poison and is readily absorbed through the respiratory tract, the gastrointestinal tract, or through unbroken skin. It acts as a cumulative poison and dangerous levels are readily attained in air. Air saturated with mercury vapor at 20 °C contains a concentration that exceeds the toxic limit many times. The danger increases at higher temperatures. *It is therefore important that mercury be handled with great care.* Containers of mercury should be securely covered and spillage should be avoided. If it is necessary to heat mercury or mercury compounds, it should be done in a well-ventilated hood. Methyl mercury is a dangerous pollutant and is now widely found in water and streams. The triple point of mercury, -38.8344 °C, is a fixed point on the International Temperature Scale (ITS-90).

Molybdenum — (Gr. *molybdos*, lead), Mo. Before Scheele recognized molybdenite as a distinct ore of a new element in 1778, it was confused with graphite and lead ore. The metal was prepared in an impure form in 1782 by Hjelm. Molybdenum does not occur native, but is obtained principally from *molybdenite* (MoS_2). *Wulfenite* (PbMoO_4) and *powellite* ($\text{Ca}(\text{Mo,W})\text{O}_4$) are also minor commercial ores. Molybdenum is also recovered as a by-product of copper and tungsten mining operations. The U.S., Canada, Chile, and China produce most of the world's molybdenum ores. The metal is prepared from the powder made by the hydrogen reduction of purified molybdc trioxide or ammonium molybdate. The metal is silvery white, very hard, but is softer and more ductile than tungsten. It has a high elastic modulus, and only tungsten and tantalum, of the more readily available metals, have higher melting points. It is a valuable alloying agent, as it contributes to the hardenability and toughness of quenched and tempered steels. It also improves the strength of steel at high temperatures. It is used in certain nickel-based alloys, such as the Hastelloys[®] which are heat-resistant and corrosion-resistant to chemical solutions. Molybdenum oxidizes at elevated temperatures. The metal has found application as electrodes for electrically heated glass furnaces and forehearth. It is also used in nuclear energy applications and for missile and aircraft parts. Molybdenum is

valuable as a catalyst in the refining of petroleum. It has found application as a filament material in electronic and electrical applications. Molybdenum is an essential trace element in plant nutrition. Some lands are barren for lack of this element in the soil. Molybdenum sulfide is useful as a lubricant, especially at high temperatures where oils would decompose. Almost all ultrahigh strength steels with minimum yield points up to 300,000 lb/in² contain molybdenum in amounts from 0.25% to 8%.

Moscovium — (*Moscow* Oblast, location of Dubna), Mc. First detected in 2003 at JNR, Dubna, Russia. The initial claim could not be verified, but subsequent work in 2013-2015 in Germany, the U.S., and Russia provided the necessary confirmation. IUPAC approved the name Moscovium in 2016. Its most stable isotope is ²⁸⁹Mc, with a half-life of 220 ms. Its position in the periodic table places it at the top of the group nitrogen, phosphorus, arsenic, antimony, and bismuth. However, no information is available yet of its actual chemical properties.

Neodymium — (Gr. *neos*, new, and *didymos*, twin), Nd. In 1841 Mosander extracted from *cerite* a new rose-colored oxide, which he believed contained a new element. He named the element *didymium*, as it was *an inseparable twin brother of lanthanum*. In 1885 von Welsbach separated didymium into two new elemental components, *neodymia* and *praseodymia*, by repeated fractionation of ammonium didymium nitrate. While the free metal is in *misch metal*, long known and used as a pyrophoric alloy for light flints, the element was not isolated in relatively pure form until 1925. Neodymium is present in *misch metal* to the extent of about 18%. It is present in the minerals *monazite* and *bastnasite*, which are principal sources of rare-earth metals. The element may be obtained by separating neodymium salts from other rare earths by ion-exchange or solvent extraction techniques, and by reducing anhydrous halides such as NdF_3 with calcium metal. Other separation techniques are possible. The metal has a bright silvery metallic luster. Neodymium is one of the more reactive rare-earth metals and quickly tarnishes in air, forming an oxide that splits off and exposes metal to oxidation. The metal, therefore, should be kept under light mineral oil or sealed in a plastic material. Neodymium exists in two allotropic forms, with a transformation from a double hexagonal to a body-centered cubic structure taking place at 855 °C. Didymium, of which neodymium is a component, is used for coloring glass to make welder's goggles. By itself, neodymium colors glass delicate shades ranging from pure violet through wine-red and warm gray. Light transmitted through such glass shows unusually sharp absorption bands. The glass has been used in astronomical work to produce sharp bands by which spectral lines may be calibrated. Glass containing neodymium can be used as a laser material. Neodymium salts are used as a colorant for enamels. The element is also being used with iron and boron to produce extremely strong magnets.

Neon — (Gr. *neos*, new), Ne. Discovered by Ramsay and Travers in 1898. Neon is a rare gaseous element present in the atmosphere to the extent of 1 part in 65,000 of air. It is obtained by liquefaction of air and separated from the other gases by fractional distillation. It is very inert

element; no stable compounds of neon have been prepared. In a vacuum discharge tube, neon glows reddish orange. Of all the rare gases, the discharge of neon is the most intense at ordinary voltages and currents. The largest use of neon is in advertising signs. It is also used to make high-voltage indicators and lightning arrestors. Neon and helium were used in the first gas lasers. Liquid neon finds some use as an economical cryogenic refrigerant. It has over 40 times more refrigerating capacity per unit volume than liquid helium and more than three times that of liquid hydrogen.

Neptunium — (Planet *Neptune*), Np. Neptunium was the first synthetic transuranium element of the actinide series discovered; the isotope ^{239}Np was produced by McMillan and Abelson in 1940 at Berkeley, California, as the result of bombarding uranium with cyclotron-produced neutrons. The isotope ^{237}Np (half-life of 2.14×10^6 years) is currently obtained in gram quantities as a by-product from the production of plutonium in nuclear reactors. Trace quantities of the element are actually found in nature due to transmutation reactions in uranium ores produced by the neutrons which are present. Neptunium metal is prepared by the reduction of NpF_3 with barium or lithium vapor at about 1200°C . It has a silvery appearance, is chemically reactive, and exists in at least three structural modifications: α -neptunium, orthorhombic; β -neptunium (above 280°C), tetragonal; and γ -neptunium (above 576°C), cubic. Neptunium has four ionic oxidation states in solution: Np^{+3} (pale purple), analogous to the rare earth ion Pm^{+3} ; Np^{+4} (yellow green); NpO^+ (green blue); and NpO^{++} (pale pink). These latter oxygenated species are in contrast to the rare earths that exhibit only simple ions of the (II), (III), and (IV) oxidation states in aqueous solution. The element forms tri- and tetrahalides such as NpF_3 , NpF_4 , NpCl_4 , NpBr_3 , NpI_3 , and oxides of various compositions such as are found in the uranium-oxygen system, including Np_3O_8 and NpO_2 .

Nickel — (Ger. *Nickel*, Satan or Old Nick's and from *kupfernickel*, Old Nick's copper), Ni. Discovered by Cronstedt in 1751 in *kupfernickel* (*niccolite*). Nickel is found as a constituent in most meteorites and often serves as one of the criteria for distinguishing a meteorite from other minerals. Iron meteorites, or *siderites*, may contain iron alloyed with from 5% to nearly 20% nickel. Nickel is obtained commercially from *pentlandite* and *pyrrhotite* of the Sudbury region of Ontario, a district that produces much of the world's nickel. It is now thought that the Sudbury deposit is the result of an ancient meteorite impact. Large deposits of nickel, cobalt, and copper have been developed at Voisey's Bay, Labrador. Other deposits of nickel are found in Russia, New Caledonia, Australia, Cuba, Indonesia, and elsewhere. Nickel is silvery white and takes on a high polish. It is hard, malleable, ductile, somewhat ferromagnetic, and a fair conductor of heat and electricity. It belongs to the iron-cobalt group of metals and is chiefly valuable for the alloys it forms. It is extensively used for making stainless steel and other corrosion-resistant alloys such as Invar, Monel, Inconel, and the Hastelloys. Tubing made of a copper-nickel alloy is used in desalination plants for converting sea water into fresh water. Nickel is also now used extensively in coinage and in making

nickel steel for armor plate and burglarproof vaults, and is a component in Nichrome, Permalloy, and constantan. Nickel added to glass gives a green color. Nickel plating is often used to provide a protective coating for other metals, and finely divided nickel is a catalyst for hydrogenating vegetable oils. It is also used in ceramics, in the manufacture of Alnico magnets, and in batteries. The sulfate and the oxides are important compounds. Nickel sulfide fume and dust, as well as other nickel compounds, are carcinogens.

Nihonium — (*Nihon*, a word for Japan), Nh. Priority for the discovery of Element 113 has been given to the RIKEN in Japan, which published evidence in 2004. Similar evidence was obtained at Dubna in Russia at about the same time. IUPAC confirmed the name nihonium in 2016. The most stable isotope, ^{286}Nh , has a half-life of 20 s. Nihonium falls in the boron, aluminum, etc., group, but here is no chemical evidence yet on the extent to which its properties differ from the lower members of the group.

Niobium — (*Niobe*, daughter of Tantalus); sometimes called Columbium (*Columbia*, name for America), Nb. Discovered in 1801 by Hatchett in an ore sent to England more than a century before by John Winthrop the Younger, first governor of Connecticut. The metal was first prepared in 1864 by Blomstrand, who reduced the chloride by heating it in a hydrogen atmosphere. The name *niobium* was adopted by the International Union of Pure and Applied Chemistry in 1950 after 100 years of controversy. Most leading chemical societies and government organizations refer to it by this name. Some metallurgists and commercial producers, however, still refer to the metal as "columbium." The element is found in *niobite* (or *columbite*), *niobite-tantalite*, *pyrochlore*, and *euxenite*. Large deposits of niobium have been found associated with carbonatites (carbon-silicate rocks), as a constituent of pyrochlore. Extensive ore reserves are found in Canada, Brazil, Congo-Kinshasa, Rwanda, and Australia. The metal can be isolated from tantalum, and prepared in several ways. It is a shiny, white, soft, and ductile metal, and takes on a bluish cast when exposed to air for a long time at room temperature. The metal starts to oxidize in air at 200°C , and when processed at even moderate temperatures must be placed in a protective atmosphere. It is used in arc welding rods for stabilized grades of stainless steel. Thousands of pounds of niobium have been used in advanced air frame systems such as were used in the Gemini space program. It has also found use in super-alloys for applications such as jet engine components, rocket subassemblies, and heat-resisting equipment. The element has superconductive properties; superconductive magnets made with Nb-Zr wire retain their superconductivity in strong magnetic fields.

Nitrogen — (L. *nitrum*, Fr. *nitre*, native soda; *-genes*, producing), N. Discovered by Daniel Rutherford in 1772, but Scheele, Cavendish, Priestley, and others about the same time studied "burnt or dephlogisticated air," as air without oxygen was then called. Nitrogen makes up 78% of the air, by volume. The atmosphere of Mars, by comparison, is 2.7% nitrogen. The estimated amount of this element in our atmosphere is more than 4000 trillion tons. From this inexhaustible source it can be obtained by liquefaction and fractional distillation. Nitrogen molecules

give the orange-red, blue-green, blue-violet, and deep violet shades to the aurora. The element is so inert that Lavoisier named it *azote*, meaning without life, yet its compounds are so active as to be most important in foods, poisons, fertilizers, and explosives. Nitrogen can be also easily prepared by heating a water solution of ammonium nitrite. Nitrogen, as a gas, is colorless, odorless, and a generally inert element. As a liquid it is also colorless and odorless, and is similar in appearance to water. Two allotropic forms of solid nitrogen exist, with the transition from the α to the β form taking place at -237°C . When nitrogen is heated, it combines directly with magnesium, lithium, or calcium; when mixed with oxygen and subjected to electric sparks, it forms first nitric oxide (NO) and then the dioxide (NO_2); when heated under pressure with a catalyst with hydrogen, ammonia is formed (Haber process). The ammonia thus formed is of the utmost importance as it is used in fertilizers, and it can be oxidized to nitric acid (Ostwald process). The ammonia industry is the largest consumer of nitrogen. Large amounts are also used by the electronics industry, which uses the gas as a blanketing medium during production of such components as transistors, diodes, etc. Large quantities of nitrogen are used in annealing stainless steel and other steel mill products. The drug industry also uses large quantities. Nitrogen is used as a refrigerant both for the immersion freezing of food products and for transportation of foods. Liquid nitrogen is also used in missile work as a purge for components, insulators for space chambers, etc., and by the oil industry to build up pressure in wells to force crude oil upward. Sodium and potassium nitrates are formed by the decomposition of organic matter with compounds of the metals present. In certain dry areas of the world these saltpeters are found in quantity. Ammonia, nitric acid, the nitrates, the five oxides (N_2O , NO, N_2O_3 , NO_2 , and N_2O_5), TNT, the cyanides, etc., are but a few of the important compounds.

Nobelium — (Alfred Nobel [1833–1896], inventor of dynamite), No. Several claims to the discovery of Element-102 were made in the 1957 to 1966 period, leading to a considerable amount of controversy and disputes over naming the element. The disputes were settled in 1966 with definitive evidence produced at the Joint Institute for Nuclear Research at Dubna. Although it had been used much earlier, the name Nobelium was finally ratified by IUPAC in 1994. ^{259}No has a half-life of 58 minutes. The chemical behavior is expected to be similar to ytterbium.

Oganesson — (Yuri Oganessian, Russian leader in heavy element research), Og. Element-118, the heaviest element so far found in the periodic table, was first detected in 2002 by Russian and American workers at JINR, Dubna. The name oganesson was approved by IUPAC in 2016. Only three or four atoms on ^{295}Og (half-life about 1 ms) have been produced. Considering its position in the periodic table, where it falls in the noble gases group, one might expect oganesson to be an unreactive gas at normal conditions. However, theoretical calculations suggest that it is a solid and possibly very reactive. Thus it might exhibit valences of +2 and +4, as well a zero.

Osmium — (Gr. *osme*, a smell), Os. Discovered in 1803 by Tennant in the residue left when crude platinum is dissolved by *aqua regia*. Osmium occurs in *iridosmine* and

in platinum-bearing river sands of the Urals, North America, and South America. It is also found in the nickel-bearing ores of the Sudbury, Ontario, region along with other platinum metals. While the quantity of platinum metals in these ores is very small, the large tonnages of nickel ores processed make commercial recovery possible. The metal is lustrous, bluish white, extremely hard, and brittle even at high temperatures. It has the highest melting point and the lowest vapor pressure of the platinum group. The metal is very difficult to fabricate, but the powder can be sintered in a hydrogen atmosphere at a temperature of 2000°C . The solid metal is not affected by air at room temperature, but the powdered or spongy metal slowly gives off osmium tetroxide, which is a powerful oxidizing agent and has a strong smell. The tetroxide is highly toxic, and boils at 130°C . Concentrations in air as low as 10^{-7} g/m^3 can cause lung congestion, skin damage, or eye damage. The tetroxide has been used to detect fingerprints and to stain fatty tissue for microscope slides. The metal is almost entirely used with other metals of the platinum group to produce very hard alloys for fountain pen tips, instrument pivots, and electrical contacts. The measured densities of iridium and osmium seem to indicate that osmium is slightly more dense than iridium, so osmium is generally credited with being the heaviest known element.

Oxygen — (Gr. *oxys*, sharp, acid, and *-genes*, forming; acid former), O. For many centuries, workers occasionally realized air was composed of more than one component. The behavior of oxygen and nitrogen as components of air led to the advancement of the phlogiston theory of combustion, which captured the minds of chemists for a century. Oxygen was prepared by several workers, including Bayen and Borch, but they did not know how to collect it, did not study its properties, and did not recognize it as an elementary substance. Priestley is generally credited with its discovery, although Scheele also discovered it independently. Oxygen is the third most abundant element found in the sun, and it plays a part in the carbon–nitrogen cycle, one process thought to give the sun and stars their energy. Oxygen under excited conditions is responsible for the bright red and yellow-green colors of the aurora. Oxygen, as a gaseous element, forms 21% of the atmosphere by volume from which it can be obtained by liquefaction and fractional distillation. The atmosphere of Mars contains about 0.13% oxygen. The element and its compounds make up 49.2%, by weight, of the Earth's crust. About two-thirds of the mass of the human body and nine-tenths of water is oxygen. In the laboratory it can be prepared by the electrolysis of water or by heating potassium chlorate with manganese dioxide as a catalyst. The gas is colorless, odorless, and tasteless. The liquid and solid forms are a pale blue color and are strongly paramagnetic. Ozone (O_3), a highly active compound, is formed by the action of an electrical discharge or ultraviolet light on oxygen. Ozone's presence in the atmosphere (amounting to the equivalent of a layer 3 mm thick at ordinary pressures and temperatures) is of vital importance in preventing the harmful ultraviolet rays of the sun from reaching the Earth's surface. The use of certain halogenated compounds that have a detrimental effect on this ozone layer has been phased out by international

agreement. Ozone is toxic and exposure should not exceed 0.1ppm. Undiluted ozone has a bluish color. Liquid ozone is bluish black, and solid ozone is violet-black. Oxygen is very reactive and capable of combining with most elements. It is a component of hundreds of thousands of organic compounds. It is essential for respiration of all plants and animals and for practically all combustion. In hospitals it is frequently used to aid respiration of patients. Its atomic weight was used as a standard until 1961 when the International Union of Pure and Applied Chemistry adopted carbon 12 as the new basis. Commercial oxygen consumption in the U.S. is estimated to be 20 million short tons per year and the demand is expected to increase. Oxygen enrichment of steel blast furnaces accounts for the greatest use of the gas. Large quantities are also used in making synthesis gas for ammonia and methanol, ethylene oxide, and for oxy-acetylene welding. Air separation plants produce about 99% of the gas, electrolysis plants about 1%.

Palladium — (named after the asteroid *Pallas*, discovered about the same time; Gr. *Pallas*, goddess of wisdom), Pd. Discovered in 1803 by Wollaston. Palladium is found along with platinum and other metals of the platinum group in deposits of Russia, South Africa, Canada (Ontario), and elsewhere. It is frequently found associated with the nickel-copper deposits such as those found in Ontario. Its separation from the platinum metals depends upon the type of ore in which it is found. It is a steel-white metal, does not tarnish in air, and is the least dense and lowest melting of the platinum group of metals. When annealed, it is soft and ductile; cold working greatly increases its strength and hardness. Palladium is attacked by nitric and sulfuric acid. At room temperatures the metal has the unusual property of absorbing up to 900 times its own volume of hydrogen. Hydrogen readily diffuses through heated palladium and this provides a means of purifying the gas. Finely divided palladium is a good catalyst for hydrogenation and dehydrogenation reactions. It is alloyed and used in jewelry trades. White gold is an alloy of gold decolorized by the addition of palladium. Like gold, palladium can be beaten into leaf as thin as 1/250,000 in. The metal is used in dentistry, watchmaking, and in making surgical instruments and electrical contacts. Palladium has been substituted for higher priced platinum in some catalytic converters. Palladium, however, is less resistant to poisoning by sulfur and lead than platinum.

Phosphorus — (Gr. *phosphoros*, light bearing; ancient name for the planet Venus when appearing before sunrise), P. Discovered in 1669 by Brand, who prepared it from urine. Phosphorus exists in several allotropic forms, the most common of which are white (or yellow), red, and black (or violet). White phosphorus has two modifications: α and β with a transition temperature at -76.9°C . Red and black phosphorus have amorphous structures. Never found free in nature, it is widely distributed in combination with minerals. *Phosphate* rock, which contains the mineral *apatite*, an impure tricalcium phosphate, is an important source of the element. Large deposits are found in Russia, China, Morocco, and in the United States in Florida, Tennessee, Utah, and Idaho. Phosphorus is an essential ingredient of all cell protoplasm, nervous tissue, and bones, and phosphate groups

provide a key linkage in the DNA chain. Ordinary phosphorus is a waxy white solid; when pure it is colorless and transparent. It is insoluble in water, but soluble in carbon disulfide. It takes fire spontaneously in air, burning to the pentoxide. It is very poisonous, 50 mg constituting an approximate fatal dose. White phosphorus should be kept under water, as it is dangerously reactive in air, and it should be handled with forceps, as contact with the skin may cause severe burns. When exposed to sunlight or when heated in its own vapor to 250°C , it is converted to the red variety, which does not phosphoresce in air as does the white form. Red phosphorus does not ignite spontaneously and it is not as dangerous as white phosphorus. It should, however, be handled with care as it does convert to the white form at some temperatures and it emits highly toxic fumes of the oxides of phosphorus when heated. The red modification is fairly stable, sublimes with a vapor pressure of 1 atm at 431°C , and is used in the manufacture of safety matches, pyrotechnics, pesticides, incendiary shells, smoke bombs, tracer bullets, etc. White phosphorus may be made by several methods. By one process, tricalcium phosphate, the essential ingredient of phosphate rock, is heated in the presence of carbon and silica in an electric furnace or fuel-fired furnace. Elementary phosphorus is liberated as vapor and may be collected under water. If desired, the phosphorus vapor and carbon monoxide produced by the reaction can be oxidized at once in the presence of moisture to produce phosphoric acid, an important compound in making super-phosphate fertilizers. In recent years, concentrated phosphoric acids, which may contain as much as 70% to 75% P_2O_5 , have become of great importance to agriculture and farm production. World-wide demand for fertilizers has caused record phosphate production. Phosphates are used in the production of special glasses, such as those used for sodium lamps. Bone-ash, calcium phosphate, is also used to produce fine chinaware and monocalcium phosphate is used in baking powder. Phosphorus is also important in the production of steels, phosphor bronze, and many other products. Trisodium phosphate is important as a cleaning agent, as a water softener, and for preventing boiler scale and corrosion of pipes and boiler tubes. Organic compounds of phosphorus are important.

Platinum — (It. *platina*, silver), P. Discovered in South America by Ulloa in 1735 and by Wood in 1741. The metal was used by pre-Columbian Indians. Platinum occurs native, accompanied by small quantities of iridium, osmium, palladium, ruthenium, and rhodium, all belonging to the same group of metals. These are found in the alluvial deposits of the Ural Mountains and in Colombia. *Sperrylite* (PtAs_2), occurring with the nickel-bearing deposits of Sudbury, Ontario, is a source of a considerable amount of the metal. The large production of nickel offsets there being only one part of the platinum metals in 2 million parts of ore. The largest supplier of the platinum group of metals is South Africa, followed by Russia and Canada. Platinum is a beautiful silvery-white metal when pure and is malleable and ductile. It has a coefficient of expansion almost equal to that of soda-lime-silica glass, and is therefore used to make sealed electrodes in glass systems. The metal does not oxidize

in air at any temperature, but is corroded by halogens, cyanides, sulfur, and caustic alkalis. It is insoluble in hydrochloric and nitric acid, but dissolves when they are mixed as *aqua regia*, forming chloroplatinic acid (H_2PtCl_6), an important compound. The metal is used extensively in jewelry, wire, and vessels for laboratory use, and in many valuable instruments including thermocouple elements. It is also used for electrical contacts, corrosion-resistant apparatus, and in dentistry. Platinum-cobalt alloys have magnetic properties. One such alloy made of 76.7% Pt and 23.3% Co, by weight, is a more powerful magnet than Alnico V. Platinum resistance wires are used for constructing high-temperature electric furnaces. The metal is used for coating missile nose cones, jet engine fuel nozzles, etc., which must perform reliably for long periods of time at high temperatures. The metal like palladium, absorbs large volumes of hydrogen, retaining it at ordinary temperatures but giving it up at red heat. In the finely divided state platinum is an excellent catalyst, having long been used in the contact process for producing sulfuric acid. It is also used as a catalyst in cracking petroleum products. There is also much current interest in the use of platinum as a catalyst in fuel cells and in its use in catalytic converters for automobiles. Platinum anodes are extensively used in cathodic protection systems for large ships and ocean-going vessels, pipelines, steel piers, etc. Hydrogen and oxygen explode in the presence of platinum. Pure platinum wire will glow red hot when placed in the vapor of methyl alcohol. It acts here as a catalyst, converting the alcohol to formaldehyde.

Plutonium — (planet *Pluto*), Pu. Plutonium was the second transuranium element of the actinide series to be discovered. The isotope ^{238}Pu was produced in 1940 by Seaborg, McMillan, Kennedy, and Wahl by deuteron bombardment of uranium in the 60-inch cyclotron at Berkeley, California. Plutonium also exists in trace quantities in naturally occurring uranium ores. It is formed in much the same manner as neptunium, by irradiation of natural uranium with the neutrons that are present. By far of greatest importance is the isotope Pu^{239} , with a half-life of 24,100 years, produced in extensive quantities in nuclear reactors from natural uranium. Plutonium has assumed the position of dominant importance among the transuranium elements because of its use as an explosive ingredient in nuclear weapons and the place it holds as a key material in the development of industrial sources of nuclear power. One kilogram is equivalent to about 22 million kilowatt hours of heat energy. The complete detonation of a kilogram of plutonium produces an explosive equal to about 20,000 tons of chemical explosive. Its importance depends on the nuclear property of being readily fissionable with neutrons and its availability in quantity. The various nuclear applications of plutonium are well known. ^{238}Pu was used in the Apollo lunar missions to power seismic and other equipment on the lunar surface. As with neptunium and uranium, plutonium metal can be prepared by reduction of the trifluoride with alkaline-earth metals. The metal has a silvery appearance and takes on a yellow tarnish when slightly oxidized. It is chemically reactive. A relatively large piece of plutonium is warm to the touch because of the energy given off in alpha decay. Larger pieces will

produce enough heat to boil water. The metal readily dissolves in concentrated hydrochloric acid, hydroiodic acid, or perchloric acid with formation of the Pu^{+3} ion. The metal exhibits six allotropic modifications having various crystalline structures. The densities of these vary from 16.0 to 19.7 g/cm^3 . Plutonium also exhibits four ionic valence states in aqueous solutions: Pu^{+3} (blue lavender), Pu^{+4} (yellow brown), PuO^+ (pink?), and PuO^{+2} (pink orange). The ion PuO^+ is unstable in aqueous solutions, disproportionating into Pu^{+4} and PuO^{+2} . The Pu^{+4} thus formed, however, oxidizes the PuO^+ into PuO^{+2} , itself being reduced to Pu^{+3} , giving finally Pu^{+3} and PuO^{+2} . Plutonium forms binary compounds with oxygen (PuO , PuO_2 , and intermediate oxides of variable composition); with the halides (PuF_3 , PuF_4 , PuCl_3 , PuBr_3 , PuI_3); and with carbon, nitrogen, and silicon (PuC , PuN , PuSi_2). Oxyhalides are also well known: PuOCl , PuOBr , PuOI . Because of the high rate of emission of alpha particles and the element being specifically absorbed by bone marrow, plutonium, as well as all of the other transuranium elements except neptunium, are radiological poisons and must be handled with very special equipment and precautions. Plutonium is a very dangerous radiological hazard. Precautions must also be taken to prevent the unintentional formation of a critical mass. Plutonium in liquid solution is more likely to become critical than solid plutonium.

Polonium — (Poland, native country of Mme. Curie [1867–1934]), Po. Polonium was the first element discovered by Mme. Curie in 1898, while seeking the cause of radioactivity of pitchblende from Joachimsthal, Bohemia. Polonium is a very rare natural element. Uranium ores contain only about 100 μg of the element per ton. Its abundance is only about 0.2% of that of radium. In 1934, it was found that when natural bismuth (^{209}Bi) was bombarded by neutrons, ^{210}Bi , the parent of polonium, was obtained. Milligram amounts of polonium may now be prepared this way, by using the high neutron fluxes of nuclear reactors. Polonium is a low-melting, fairly volatile metal, 50% of which is vaporized in air in 45 hours at 55 °C. It is an alpha emitter with a half-life of 138.39 days. A milligram emits as many alpha particles as 5 g of radium. The energy released by its decay is so large (140 W/g) that a capsule containing about half a gram reaches a temperature above 500 °C. The capsule also presents a contact gamma-ray dose rate of 0.012 Gy/h. A few curies (1 curie = 3.7×10^{10} Bq) of polonium exhibit a blue glow, caused by excitation of the surrounding gas. Because almost all alpha radiation is stopped within the solid source and its container, giving up its energy, polonium has attracted attention for uses as a lightweight heat source for thermoelectric power in space satellites. Polonium-210 is the most readily available isotope. Metallic polonium has been prepared from polonium hydroxide and some other polonium compounds in the presence of concentrated aqueous or anhydrous liquid ammonia. Two allotropic modifications are known to exist. Polonium is readily dissolved in dilute acids, but is only slightly soluble in alkalis. Polonium salts of organic acids char rapidly; halide amines are reduced to the metal. Polonium can be mixed or alloyed with beryllium to provide a source of neutrons. It has been used in devices for eliminating static charges in textile mills,

etc.; however, beta sources are more commonly used and are less dangerous. It is also used on brushes for removing dust from photographic films. The polonium for these is carefully sealed and controlled, minimizing hazards to the user. Polonium-210 is very dangerous to handle in even milligram or microgram amounts, and special equipment and strict control are necessary. Damage arises from the complete absorption of the energy of the alpha particles into tissue. The maximum permissible body burden for ingested polonium is only $0.03 \mu\text{Ci}$, which represents a particle weighing only 6.8×10^{-12} g. Weight for weight it is about 2.5×10^{11} times as toxic as hydrocyanic acid.

Potassium — (English, *potash* — pot ashes; L. *kalium*, Arab. *qali*, alkali), K. Discovered in 1807 by Davy, who obtained it from caustic potash (KOH); this was the first metal isolated by electrolysis. The metal is the seventh most abundant and makes up about 2.4% by weight of the Earth's crust. Most potassium minerals are insoluble and the metal is obtained from them only with great difficulty. Certain minerals, however, such as *sylvite*, *carnallite*, *langbeinite*, and *polyhalite* are found in ancient lake and sea beds and form rather extensive deposits from which potassium and its salts can readily be obtained. Potash is mined in Germany, New Mexico, California, Utah, and elsewhere. Large deposits of potash, found at a depth of some 1000 m in Saskatchewan, promise to be important in coming years. Potassium is also found in the ocean, but is present only in relatively small amounts compared to sodium. The greatest demand for potash has been in its use for fertilizers. Potassium is an essential constituent for plant growth and it is found in most soils. Potassium is never found free in nature, but is obtained by electrolysis of the hydroxide, much in the same manner as prepared by Davy. Thermal methods also are commonly used to produce potassium (such as by reduction of potassium compounds with CaC_2 , C, Si, or Na). It is one of the most reactive and electropositive of metals. Except for lithium, it is the lightest known metal. It is soft, easily cut with a knife, and is silvery in appearance immediately after a fresh surface is exposed. It rapidly oxidizes in air and should be preserved in a mineral oil. As with other metals of the alkali group, it decomposes in water with the evolution of hydrogen. It catches fire spontaneously on water. Potassium and its salts impart a violet color to flames. An alloy of sodium and potassium (NaK) is used as a heat-transfer medium. Many potassium salts are of utmost importance, including the hydroxide, nitrate, carbonate, chloride, chlorate, bromide, iodide, cyanide, sulfate, chromate, and dichromate.

Praseodymium — (Gr. *prasios*, green, and *didymos*, twin), Pr. In 1841 Mosander extracted the rare earth *didymia* from *lanthana*; in 1879, Lecoq de Boisbaudran isolated a new earth, *samarium*, from didymia obtained from the mineral *samarite*. Six years later, in 1885, von Welsbach separated didymia into two others, *praseodymia* and *neodymia*, which gave salts of different colors. As with other rare earths, compounds of these elements in solution have distinctive sharp spectral absorption bands or lines, some of which are only a few Ångströms wide. The element occurs along with other rare-earth elements in a variety of minerals. *Monazite* and *bastnasite* are the

two principal commercial sources of the rare-earth metals. Ion-exchange and solvent extraction techniques have led to much easier isolation of the rare earths and the cost has dropped greatly. Praseodymium can be prepared by several methods, such as by calcium reduction of the anhydrous chloride or fluoride. Misch metal, used in making cigarette lighters, contains about 5% praseodymium metal. Praseodymium is soft, silvery, malleable, and ductile. It was first prepared in relatively pure form in 1931. It is somewhat more resistant to corrosion in air than europium, lanthanum, cerium, or neodymium, but it does develop a green oxide coating that splits off when exposed to air. As with other rare-earth metals it should be kept under a light mineral oil or sealed in plastic. The rare-earth oxides, including Pr_2O_3 , are among the most refractory substances known. Salts of praseodymium are used to color glasses and enamels; when mixed with certain other materials, praseodymium produces an intense and unusually clean yellow color in glass. Didymium glass, of which praseodymium is a component, is a colorant for welder's goggles.

Promethium — (*Prometheus*, who, according to mythology, stole fire from heaven), Pm. In 1902 Branner predicted the existence of an element between neodymium and samarium, and this prediction was confirmed by Moseley in 1914. Unsuccessful searches were made for this predicted element over two decades, and various investigators proposed the names "illinium," "florentium," and "cyclonium" for this element. In 1941, workers at Ohio State University irradiated neodymium and praseodymium with neutrons, deuterons, and alpha particles, and produced several new radioactivities, which most likely were those of Element 61. Wu and Segre, and Bethe, in 1942, confirmed the formation; however, chemical proof of the production of Element 61 was lacking because of the difficulty in separating the rare earths from each other at that time. In 1945, Marinovsky, Glendenin, and Coryell made the first chemical identification by using ion-exchange chromatography. Their work was done by fission of uranium and by neutron bombardment of neodymium. These investigators named the newly discovered element. Searches for the element on Earth have been fruitless, and it now appears that promethium is completely missing from the Earth's crust. Promethium, however, has been reported to be in the spectrum of the star HR⁴⁶⁵ in Andromeda. It must be formed near the star's surface, for no known isotope of promethium has a half-life longer than 17.7 years. That isotope, Promethium-145, is the most useful. Promethium-145 has a specific activity of 940 Ci/g. It is a soft beta emitter; although no gamma rays are emitted, X-radiation can be generated when beta particles impinge on elements of a high atomic number, and great care must be taken in handling it. Promethium salts luminesce in the dark with a pale blue or greenish glow, due to their high radioactivity. Ion-exchange methods led to the preparation of about 10 g of promethium from atomic reactor fuel processing wastes in early 1963. Little is yet known about the properties of metallic promethium. Two allotropic modifications exist. The element has applications as a beta source for thickness gages, and its radiation can be absorbed by a phosphor to produce light. Light produced in this manner can be

used for signs or signals that require dependable operation; it can be used as a nuclear-powered battery by capturing light in photocells that convert it into electric current. Such a battery, using ^{147}Pm , would have a useful life of about 5 years. It is being used for fluorescent lighting starters and coatings for self-luminous watch dials. Promethium shows promise as a portable x-ray source, and it may become useful as a heat source to provide auxiliary power for space probes and satellites. More than 30 promethium compounds have been prepared. Most are colored.

Protactinium — (Gr. *protos*, first), Pa. The first isotope of Element 91 to be discovered was ^{234}Pa , also known as UX_2 , a short-lived member of the naturally occurring ^{238}U decay series. It was identified by K. Fajans and O. H. Gohring in 1913 and they named the new element *brevium*. When the longer-lived isotope ^{231}Pa was identified by Hahn and Meitner in 1918, the name protoactinium was adopted as being more consistent with the characteristics of the most abundant isotope. Soddy, Cranson, and Fleck were also active in this work. The name *protoactinium* was shortened to *protactinium* in 1949. In 1927, Grosse prepared 2 mg of a white powder, which was shown to be Pa_2O_5 . Later, in 1934, from 0.1 g of pure Pa_2O_5 he isolated the element by two methods, one of which was by converting the oxide to an iodide and "cracking" it in a high vacuum by an electrically heated filament by the reaction $2\text{PaI}_5 \rightarrow 2\text{Pa} + 5\text{I}_2$. Protactinium has a bright metallic luster that it retains for some time in air. The element occurs in *pitchblende* to the extent of about 1 part ^{231}Pa to 10 million parts of ore. Ores from Congo-Kinshasa have about 3 ppm. The most common isotope is ^{231}Pa with a half-life of 32,500 years. A number of protactinium compounds are known, some of which are colored. The element is superconductive below 1.4 K. The element is a dangerous toxic material and requires precautions similar to those used when handling plutonium. Protactinium is one of the rarest and most expensive naturally occurring elements.

Radium — (L. *radius*, ray), Ra. Radium was discovered in 1898 by Pierre and Marie Curie in the *pitchblende* or *uraninite* of North Bohemia (Czech Republic), where it occurs. There is about 1 g of radium in 7 tons of *pitchblende*. The element was isolated in 1911 by Mme. Curie and Debierne by the electrolysis of a solution of pure radium chloride, employing a mercury cathode; on distillation in an atmosphere of hydrogen this amalgam yielded the pure metal. Originally, radium was obtained from the rich *pitchblende* ore found at Joachimsthal, Bohemia. The *carnotite* sands of Colorado furnish some radium, but richer ores are found in the Democratic Republic of Congo and the Great Bear Lake region of Canada. Radium is present in all uranium minerals, and could be extracted, if desired, from the extensive wastes of uranium processing. Large uranium deposits are located in Ontario, New Mexico, Utah, Australia, and elsewhere. Radium is obtained commercially as the bromide or chloride; it is doubtful if any appreciable stock of the pure element now exists. The pure metal is brilliant white when freshly prepared, but blackens on exposure to air, probably due to formation of the nitride. It exhibits luminescence, as do its salts; it decomposes in water and is somewhat more volatile than barium. It is a member

of the alkaline-earth group of metals. Radium imparts a carmine red color to a flame. Radium emits alpha, beta, and gamma rays and when mixed with beryllium produce neutrons. One gram of ^{226}Ra undergoes 3.7×10^{10} disintegrations per second. The *curie* (Ci) is defined as that amount of radioactivity which has the same disintegration rate as 1 g of ^{226}Ra . Radium-226, the most common isotope, has a half-life of 1599 years. One gram of radium produces about 0.0001 mL (stp) of emanation, or radon gas, per day. This is pumped from the radium and sealed in minute tubes, which are used in the treatment of cancer. One gram of radium yields about 4186 kJ of energy per year. Radium is used in producing neutron sources and in medicine for the treatment of cancer. Some of the more recently discovered radioisotopes, such as ^{60}Co , are now being used in place of radium. Some of these sources are much more powerful, and others are safer to use. Radium loses about 1% of its activity in 25 years, being transformed into elements of lower atomic weight. Lead is a final product of disintegration. Stored radium should be ventilated to prevent build-up of radon. Inhalation, injection, or body exposure to radium can cause cancer and other body disorders.

Radon — (from *radium*; called *niton* at first, L. *nitens*, shining), Rn. The element was discovered in 1900 by Dorn, who called it *radium emanation*. In 1908 Ramsay and Gray, who named it *niton*, isolated the element and determined its density, finding it to be the heaviest known gas. It is essentially inert and occupies the last place in the zero group of gases in the Periodic Table. Since 1923, it has been called radon. Radon-222, coming from radium, has a half-life of 3.823 days and is an alpha emitter; Radon-220, emanating naturally from thorium and called *thoron*, has a half-life of 55.6 s and is also an alpha emitter. Radon-219 emanates from actinium and is called *actinon*. It has a half-life of 3.96 s and is also an alpha emitter. It is estimated that every square mile of soil to a depth of 6 inches contains about 1 g of radium, which releases radon in tiny amounts to the atmosphere. Radon is present in some spring waters, such as those at Hot Springs, Arkansas. On the average, one part of radon is present to 1×10^8 part of air. At ordinary temperatures radon is a colorless gas; when cooled below the freezing point, radon exhibits a brilliant phosphorescence which becomes yellow as the temperature is lowered and orange-red at the temperature of liquid air. It has been reported that fluorine reacts with radon, forming radon fluoride. Radon clathrates have also been reported. Radon is still produced for therapeutic use by a few hospitals by pumping it from a radium source and sealing it in minute tubes, called seeds or needles, for application to patients. This practice has now been largely discontinued as hospitals can order the seeds directly from suppliers, who make up the seeds with the desired activity for the day of use. Care must be taken in handling radon, as with other radioactive materials. The main hazard is from inhalation of the element and its solid daughters, which are collected on dust in the air. Good ventilation should be provided where radium, thorium, or actinium is stored to prevent build-up of this element. Radon build-up is a health consideration in uranium mines, and build-up in homes is a major

concern in some areas. Many deaths from lung cancer are caused by radon exposure.

Rhenium — (L. *Rhenus*, Rhine), Re. Discovery of rhenium is generally attributed to Noddack, Tacke, and Berg, who announced in 1925 they had detected the element in platinum ores and *columbite*. They also found the element in *gadolinite* and *molybdenite*. By working up 660 kg of molybdenite they were able in 1928 to extract 1 g of rhenium. Rhenium does not occur free in nature or as a compound in a distinct mineral species. It is, however, widely spread throughout the Earth's crust to the extent of about 0.001 ppm. Commercial rhenium in the U.S. today is obtained from molybdenite roaster-flue dusts obtained from copper-sulfide ores mined in the vicinity of Miami, Arizona, and other places in Arizona and Utah. Some molybdenites contain from 0.002% to 0.2% rhenium. It is estimated that in 1999 about 16,000 kg of rhenium was being produced. The total estimated world reserve of rhenium is 11,000,000 kg. Natural rhenium is a mixture of two isotopes, one of which is radioactive with a very long half-life. Rhenium metal is prepared by reducing ammonium perhenate with hydrogen at elevated temperatures. The element is silvery white with a metallic luster; its density is exceeded by that of only platinum, iridium, and osmium, and its melting point is exceeded only by that of tungsten and carbon. It has other useful properties. The usual commercial form of the element is a powder, but it can be consolidated by pressing and resistance-sintering in a vacuum or hydrogen atmosphere. This produces a compact shape in excess of 90% of the density of the metal. Annealed rhenium is very ductile, and can be bent, coiled, or rolled. Rhenium is used as an additive to tungsten and molybdenum-based alloys to impart useful properties. It is widely used for filaments for mass spectrographs and ion gages. Rhenium-molybdenum alloys are superconductive at 10 K. Rhenium is also used as an electrical contact material as it has good wear resistance and withstands arc corrosion. Thermocouples made of Re-W are used for measuring temperatures up to 2200 °C, and rhenium wire has been used in photoflash lamps for photography. Rhenium catalysts are exceptionally resistant to poisoning from nitrogen, sulfur, and phosphorus, and are used for hydrogenation of fine chemicals, hydrocracking, reforming, and disproportionation of olefins. Rhenium has become especially important as a catalyst for petroleum refining and in making superalloys for jet engines.

Rhodium — (Gr. *rhodon*, rose), Rh. Wollaston discovered rhodium in 1803-4 in crude platinum ore he presumably obtained from South America. Rhodium occurs native with other platinum metals in river sands of the Urals and in North and South America. It is also found with other platinum metals in the copper-nickel sulfide ores of the Sudbury, Ontario region. Although the quantity occurring here is very small, the large tonnages of nickel processed make the recovery commercially feasible. The annual world production of rhodium in 2000 was only about 9000 kg. The metal is silvery white and at red heat slowly changes in air to the sesquioxide. At higher temperatures it reverts to the element. Rhodium has a higher melting point and lower density than platinum. Its major use is as an alloying agent to harden platinum

and palladium. Such alloys are used for furnace windings, thermocouple elements, bushings for glass fiber production, and laboratory crucibles. It is useful as an electrical contact material as it has a low electrical resistance, a low and stable contact resistance, and is highly resistant to corrosion. Plated rhodium, produced by electroplating or evaporation, is exceptionally hard and is used for optical instruments. It has a high reflectance and is hard and durable. Rhodium is also used for jewelry, for decoration, and as a catalyst.

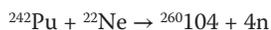
Roentgenium — (Wilhelm Roentgen, discoverer of x-rays), Rg. On December 20, 1994, scientists at GSI Darmstadt, Germany announced they had detected three atoms of a new element with 111 protons and 161 neutrons. This element was made by bombarding ^{83}Bi with ^{28}Ni . Signals of Element 111 appeared for less than 0.002 s, then decayed into lighter elements including Element $^{268}109$ and Element $^{264}107$. These isotopes had not previously been observed. In 2004 IUPAC approved the name roentgenium for Element 111. Roentgenium is expected to have properties similar to gold.

Rubidium — (L. *rubidus*, deepest red), Rb. Discovered in 1861 by Bunsen and Kirchhoff in the mineral *lepidolite* by use of spectroscopy. The element is much more abundant than was thought at one time. It is now considered to be the 16th most abundant element in the Earth's crust. Rubidium occurs in *pollucite*, *carnallite*, *leucite*, and *zinnwaldite*, which contains traces up to 1%, in the form of the oxide. It is found in lepidolite to the extent of about 1.5%, and is recovered commercially from this source. Potassium minerals, such as those found at Searles Lake, California, and potassium chloride recovered from brines in Michigan also contain the element and are commercial sources. It is also found along with cesium in the extensive deposits of *pollucite* at Bernic Lake, Manitoba. Rubidium can be liquid at room temperature. It is a soft, silvery-white metallic element of the alkali group and is the second most electropositive and alkaline element. It ignites spontaneously in air and reacts violently in water, setting fire to the liberated hydrogen. As with other alkali metals, it forms amalgams with mercury and it alloys with gold, cesium, sodium, and potassium. It colors a flame yellowish violet. Rubidium metal can be prepared by reducing rubidium chloride with calcium, and by a number of other methods. It must be kept under a dry mineral oil or in a vacuum or inert atmosphere. Naturally occurring rubidium is made of two isotopes, ^{85}Rb and ^{87}Rb . Rubidium-87 is present to the extent of 27.83% in natural rubidium and is a beta emitter with a half-life of 4.9×10^{10} years. Ordinary rubidium is sufficiently radioactive to expose a photographic film in about 30 to 60 days. Rubidium forms four oxides: Rb_2O , Rb_2O_2 , Rb_2O_3 , Rb_2O_4 . Because rubidium can be easily ionized, it has been considered for use in ion engines for space vehicles; however, cesium is somewhat more efficient for this purpose. It has also been proposed for use as a working fluid for vapor turbines and for use in a thermoelectric generator using magnetohydrodynamic principles. Rubidium has been used as a getter in vacuum tubes and as a photocell component. It has been used in making special glasses. RbAg_4I_5 has the highest room-temperature conductivity of any known

ionic crystal. This suggests use in thin film batteries and other applications.

Ruthenium — (L. *Ruthenia*, Russia), Ru. Berzelius and Osann in 1827 examined the residues left after dissolving crude platinum from the Ural Mountains in *aqua regia*. While Berzelius found no unusual metals, Osann thought he found three new metals, one of which he named ruthenium. In 1844 Klaus, generally recognized as the discoverer, showed that Osann's ruthenium oxide was very impure and that it contained a new metal. Klaus obtained 6 g of ruthenium from the portion of crude platinum that is insoluble in *aqua regia*. A member of the platinum group, ruthenium occurs native with other members of the group of ores found in the Ural Mountains and in North and South America. It is also found along with other platinum metals in small but commercial quantities in *pentlandite* of the Sudbury, Ontario, nickel-mining region, and in *pyroxinite* deposits of South Africa. The metal is isolated commercially by a complex chemical process, the final stage of which is the hydrogen reduction of ammonium ruthenium chloride, which yields a powder. The powder is consolidated by powder metallurgy techniques or by argon-arc welding. Ruthenium is a hard, white metal and has four crystal modifications. It does not tarnish at room temperatures, but oxidizes in air at about 800 °C. The metal is not attacked by hot or cold acids or *aqua regia*, but when potassium chlorate is added to the solution, it oxidizes explosively. It is attacked by halogens and by hydroxides. Ruthenium can be plated by electrodeposition or by thermal decomposition methods. The metal is one of the most effective hardeners for platinum and palladium, and is alloyed with these metals to make electrical contacts for severe wear resistance. A ruthenium-molybdenum alloy is superconductive at 10.6 K. The corrosion resistance of titanium is improved a hundredfold by addition of 0.1% ruthenium. It is a versatile catalyst. Hydrogen sulfide can be split catalytically by light using an aqueous suspension of CdS particles loaded with ruthenium dioxide. This may have application to removal of H₂S in oil refining and other industrial processes. Compounds in at least eight oxidation states have been found, but of these, the +2, +3, and +4 states are the most common. Ruthenium compounds show a marked resemblance to those of osmium. Ruthenium tetroxide, like osmium tetroxide, is highly toxic and may explode.

Rutherfordium — (Ernest Rutherford [1871–1937], New Zealand, Canadian, and British physicist); Rf. An isotope of Element-104 was produced in 1964 at the Joint Nuclear Research Institute at Dubna by bombardment of plutonium with accelerated neon ions through the following reaction:



Other isotopes were later produced at Berkeley. A long-standing naming controversy was finally settled by IUPAC in 1997 through adoption of the name Rutherfordium.

Element 104, the first *transactinide* element, is expected to have chemical properties similar to those of hafnium. Experiments have shown that it forms volatile tetrahalides, RfCl₄ and RfBr₄, as well as the oxchloride,

RfOCl₂. More complex compounds in which it shows a valence of 6 have also been produced. The pure element is expected to be a dense metal. The most stable isotope is probably ²⁶⁷Rf, with a half-life of 1.3 minutes.

Samarium — (*Samarските*, a mineral), Sm. Discovered spectroscopically by its sharp absorption lines in 1879 by Lecoq de Boisbaudran in the mineral *samarските*, named in honor of a Russian mine official, Col. Samarski. Samarium is found along with other members of the rare-earth-elements in many minerals, including *monazite* and *bastnasite*, which are commercial sources. The largest producer of rare-earth minerals is now China, followed by the U.S., India, and Russia. It occurs in monazite to the extent of 2.8%. While *misch metal* containing about 1% of samarium metal has long been used, samarium was not isolated in relatively pure form until 1901. Samarium metal can be produced by reducing the oxide with barium or lanthanum. Samarium has a bright silver luster and is reasonably stable in air. Three crystal modifications of the metal exist, with transformations at 734 and 922 °C. The metal ignites in air at about 150 °C. Natural samarium is a mixture of seven isotopes, three of which are unstable but have long half-lives. The sulfide has excellent high-temperature stability and good thermoelectric efficiencies up to 1100 °C. SmCo₅ has been used in making a permanent magnet material with a very high resistance to demagnetization. Samarium oxide has been used in optical glass to absorb infrared radiation. Samarium is used to dope calcium fluoride crystals for use in lasers. Compounds of the metal act as sensitizers for phosphors excited in the infrared; the oxide exhibits catalytic properties in the dehydration and dehydrogenation of ethyl alcohol. It is used as a neutron absorber in nuclear reactors. Little is known of the toxicity of samarium; therefore, it should be handled carefully.

Scandium — (L. *Scandia*, Scandinavia), Sc. On the basis of the Periodic System, Mendeleev predicted the existence of *ekaboron*, which would have an atomic weight between 40 of calcium and 48 of titanium. The element was discovered by Nilson in 1878 in the minerals *euxenite* and *gadolinite*, which had not yet been found anywhere except in Scandinavia. By processing 10 kg of *euxenite* and other residues of rare-earth minerals, Nilson was able to prepare about 2 g of scandium oxide of high purity. Cleve later pointed out that Nilson's scandium was identical with Mendeleev's *ekaboron*. Scandium is apparently a much more abundant element in the sun and certain stars than here on Earth. It is about the 23rd most abundant element in the sun, compared to the 50th most abundant on Earth. It is widely distributed on Earth, occurring in very minute quantities in over 800 mineral species. The blue color of beryl (aquamarine variety) is said to be due to scandium. It occurs as a principal component in the rare mineral *thortveitite*, found in Scandinavia and Malagasy. It is also found in the residues remaining after the extraction of tungsten from Zinnwald *wolframite*, and in *wiikite* and *bazzite*. Most scandium is presently being recovered from *thortveitite* or is extracted as a by-product from uranium mill tailings. Metallic scandium was first prepared in 1937 by Fischer, Brunger, and Grieneisen, who electrolyzed a eutectic melt of potassium, lithium, and scandium

chlorides at 700 to 800 °C. Tungsten wire and a pool of molten zinc served as the electrodes in a graphite crucible. Pure scandium is now produced by reducing scandium fluoride with calcium metal. The production of the first pound of 99% pure scandium metal was announced in 1960. Scandium is a silver-white metal that develops a slightly yellowish or pinkish cast upon exposure to air. It is relatively soft, and resembles yttrium and the rare-earth metals more than it resembles aluminum or titanium. It is a very light metal and has a much higher melting point than aluminum, making it of interest to designers of spacecraft. Scandium is not attacked by a 1:1 mixture of conc. HNO₃ and 48% HF. Scandium reacts rapidly with many acids. About 20 kg of scandium (as Sc₂O₃) are now being used yearly in the U.S. to produce high-intensity lights, and the radioactive isotope ⁴⁶Sc is used as a tracing agent in crude-oil refining. Scandium iodide added to mercury vapor lamps produces a highly efficient light source resembling sunlight. Little is yet known about the toxicity of scandium; therefore, it should be handled with care.

Seaborgium — (Glenn T. Seaborg [1912–1999], American chemist and nuclear physicist), Sg. The discovery of *Seaborgium*, Element 106, took place in 1974 almost simultaneously at the Lawrence-Berkeley Laboratory and at the Joint Institute for Nuclear Research at Dubna, Russia. The Berkeley Group, under direction of Ghiorso, used the Super-Heavy Ion Linear Accelerator (Super-HILAC) as a source of heavy ¹⁸O ions to bombard a 259 µg target of ²⁴⁹Cf. This resulted in the production and positive identification of ²⁶³106, which decayed with a half-life of 0.8 s by the emission of alpha particles. The Dubna Team, directed by Flerov and Organessian, produced heavy ions of ⁵⁴Cr with their 310-cm heavy-ion cyclotron to bombard ²⁰⁷Pb and ²⁰⁸Pb and found a product that decayed with a half-life of 7 ms. They assigned ²⁵⁹106 to this isotope. Other isotopes of *Seaborgium* were later identified. Two of these, ²⁶⁹Sg and ²⁷¹Sg, have half-lives of about 2 min. *Seaborgium* most likely would have properties resembling tungsten. IUPAC adopted the name *Seaborgium* in August 1997. Normally the naming of an element is not given until after the death of the person for which the element is named; however, in this case, it was named while Dr. Seaborg was still alive.

Selenium — (Gr. *Selene*, moon), Se. Discovered by Berzelius in 1817, who found it associated with tellurium, named for the Earth. Selenium is found in a few rare minerals, such as *crooksite* and *clausthalite*. In years past it has been obtained from flue dusts remaining from processing copper sulfide ores, but the anode muds from electrolytic copper refineries now provide the source of most of the world's selenium. Selenium is recovered by roasting the muds with soda or sulfuric acid, or by smelting them with soda and niter. Elemental selenium exists in several allotropic forms. Three are generally recognized, but as many as six have been claimed. Selenium can be prepared with either an amorphous or crystalline structure. The color of amorphous selenium is either red, in powder form, or black, in vitreous form. Crystalline monoclinic selenium is a deep red; crystalline hexagonal selenium, the most stable variety, is a metallic gray. The element is a member of the sulfur family and resembles sulfur both in its various

forms and in its compounds. Selenium exhibits both photovoltaic action, where light is converted directly into electricity, and photoconductive action, where the electrical resistance decreases with increased illumination. These properties have made selenium useful in the production of photocells and exposure meters for photographic use, as well as solar cells. Selenium is also able to convert a.c. electricity to d.c., and is used in rectifiers. Below its melting point, selenium is a p-type semiconductor and has found uses in electronic and solid-state applications. It was formerly used in xerography for reproducing and copying documents, but it has been replaced in this application organic photoconductors. It is used by the glass industry to decolorize glass and to make ruby-colored glasses and enamels. It is also used as a photographic toner, and as an additive to stainless steel. Elemental selenium has low toxicity, and selenium is considered to be an essential trace element for humans; however, hydrogen selenide and other selenium compounds are extremely toxic, and resemble arsenic in their physiological reactions. Hydrogen selenide in a concentration of 1.5 ppm is intolerable to man. Selenium occurs in some soils in amounts sufficient to produce serious effects on animals feeding on plants, such as locoweed, grown in such soils.

Silicon — (L. *silix*, *silicis*, flint), Si. Davy in 1800 thought silica to be a compound and not an element; later in 1811, Gay Lussac and Thenard probably prepared impure amorphous silicon by heating potassium with silicon tetrafluoride. Berzelius, generally credited with the discovery, in 1824 succeeded in preparing amorphous silicon by the same general method as used earlier, but he purified the product by removing the fluosilicates by repeated washings. Deville in 1854 first prepared crystalline silicon, the second allotropic form of the element. Silicon is present in the sun and stars and is a principal component of a class of meteorites known as "aerolites." It is also a component of *tektites*, a natural glass of uncertain origin. Silicon makes up 25.7% of the Earth's crust, by weight, and is the second most abundant element, being exceeded only by oxygen. Silicon is not found free in nature, but occurs chiefly as the oxide and as silicates. *Sand*, *quartz*, *rock crystal*, *amethyst*, *agate*, *flint*, *jasper*, and *opal* are some of the forms in which the oxide appears. *Granite*, *hornblende*, *asbestos*, *feldspar*, *clay mica*, etc., are but a few of the numerous silicate minerals. Silicon is prepared commercially by heating silica and carbon in an electric furnace, using carbon electrodes. Several other methods can be used for preparing the element. Amorphous silicon can be prepared as a brown powder, which can be easily melted or vaporized. Crystalline silicon has a metallic luster and grayish color. The Czochralski process is commonly used to produce single crystals of silicon used for solid-state devices. Hyperpure silicon can be prepared by the thermal decomposition of ultrapure trichlorosilane in a hydrogen atmosphere, and by a vacuum float zone process. This product can be doped with boron, gallium, phosphorus, or arsenic to produce semiconductors for use in transistors, solar cells, rectifiers, and other solid-state devices that are used extensively in the electronics industries. Silicon is a relatively inert element, but it is attacked by halogens and dilute alkali. Most acids,

except hydrofluoric, do not affect it. Hydrolysis and condensation of various substituted chlorosilanes can be used to produce a very great number of polymeric products, or silicones, ranging from liquids to hard, glasslike solids with many useful properties. Elemental silicon transmits more than 95% of all wavelengths of infrared light, from 1.3 to 6.7 μm . Silicon is one of man's most useful elements. In the form of sand and clay it is used to make concrete and brick; it is a useful refractory material for high-temperature work, and in the form of silicates it is used in making enamels, pottery, etc. Silica, as sand, is a principal ingredient of glass, one of the most inexpensive of materials with excellent mechanical, optical, thermal, and electrical properties. Glass can be made in a very great variety of shapes, and is used as containers, window glass, insulators, and thousands of other uses. Silicon is important in plant and animal life. Diatoms in both fresh and salt water extract silica from the water to build up their cell walls. Silica is present in ashes of plants and in the human skeleton. Silicon is an important ingredient in steel; silicon carbide is one of the most important abrasives. Miners, stonecutters, and other engaged in work where siliceous dust is breathed in large quantities often develop a serious lung disease known as *silicosis*.

Silver — (Anglo-Saxon, *Seolfor siolfur*), Ag (L. *Argentum*). Silver has been known since ancient times. It is mentioned in Genesis. Slag dumps in Asia Minor and on islands in the Aegean Sea indicate that man learned to separate silver from lead as early as 3000 B.C. Silver occurs native and in ores such as *argentite* (Ag_2S) and *horn silver* (AgCl); lead, lead-zinc, copper, gold, and copper-nickel ores are principal sources. Mexico, Canada, Peru, and the U.S. are the principal silver producers in the western hemisphere. Silver is also recovered during electrolytic refining of copper. Commercial fine silver contains at least 99.9% silver. Purities of 99.999+% are available commercially. Pure silver has a brilliant white metallic luster. It is a little harder than gold and is very ductile and malleable, being exceeded only by gold and perhaps palladium. Pure silver has the highest electrical and thermal conductivity of all metals, and possesses the lowest contact resistance. It is stable in pure air and water, but tarnishes when exposed to ozone, hydrogen sulfide, or air containing sulfur. The alloys of silver are important. Sterling silver is used for jewelry, silverware, etc., where appearance is paramount. This alloy contains 92.5% silver, the remainder being copper or some other metal. Silver was once of great importance in photography, including production of x-ray images, but that application has diminished as digital photography became popular. It is used for dental alloys and in making solder and brazing alloys, electrical contacts, and high capacity silver-zinc and silver-cadmium batteries. Silver paints are used for making printed circuits. It is used in mirror production and may be deposited on glass or metals by chemical deposition, electrodeposition, or by evaporation. When freshly deposited, it is the best reflector of visible light known, but is rapidly tarnishes and loses much of its reflectance. It is a poor reflector of ultraviolet. Silver fulminate ($\text{Ag}_2\text{C}_2\text{N}_2\text{O}_2$), a powerful explosive, is sometimes formed during the silvering process. Silver nitrate, or *lunar caustic*, is an

important silver compound. While silver itself is not considered to be toxic, most of its salts are poisonous. Silver compounds can be absorbed in the circulatory system and reduced silver deposited in the various tissues of the body. A condition, known as *argyria*, results with a greyish pigmentation of the skin and mucous membranes. Silver has germicidal effects and kills many lower organisms effectively without harm to higher animals. Silver has been used for coinage since ancient times. However, in the 20th century the U.S. and most other countries abandoned silver as a monetary standard and replaced silver coins by other metals, often alloys of copper, nickel, and zinc.

Sodium — (English, *soda*; Medieval Latin, *sodanum*, headache remedy), Na (L. *natrium*). Long recognized in compounds, sodium was first isolated by Davy in 1807 by electrolysis of caustic soda. Sodium is present in fair abundance in the sun and stars. The D lines of sodium are among the most prominent in the solar spectrum. Sodium is the sixth most abundant element on earth, comprising about 2.6% of the Earth's crust; it is the most abundant of the alkali group of metals of which it is a member. The most common compound is sodium chloride, but sodium occurs in many other minerals, such as *soda niter*, *cryolite*, *amphibole*, *zeolite*, *sodalite*, etc. It is a very reactive element and is never found free in nature. It is now obtained commercially by the electrolysis of absolutely dry fused sodium chloride. This method is much cheaper than that of electrolyzing sodium hydroxide, as was used in the past. Sodium is a soft, bright, silvery metal that floats on water, decomposing it with the evolution of hydrogen and the formation of the hydroxide. It may or may not ignite spontaneously on water, depending on the amount of oxide and metal exposed to the water. It normally does not ignite in air at temperatures below 115 °C. Sodium should be handled with respect, as it can be dangerous when improperly handled. Metallic sodium is vital in the manufacture of sodamide and esters, and in the preparation of organic compounds. The metal may be used to improve the structure of certain alloys, to descale metal, to purify molten metals, and as a heat transfer agent. An alloy of sodium with potassium, NaK, is also an important heat transfer agent. Sodium compounds are important to the paper, glass, soap, textile, petroleum, chemical, and metal industries. Soap is generally a sodium salt of certain fatty acids. The importance of common salt to animal nutrition has been recognized since prehistoric times. Among the many compounds that are of the greatest industrial importance are common salt (NaCl), soda ash (Na_2CO_3), baking soda (NaHCO_3), caustic soda (NaOH), Chile saltpeter (NaNO_3), di- and tri-sodium phosphates, sodium thiosulfate (hypo, $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$), and borax ($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$). Sodium metal should be handled with great care. It should be kept in an inert atmosphere and contact with water and other substances with which sodium reacts should be avoided.

Strontium — (*Strontian*, town in Scotland), Sr. Isolated by Davy by electrolysis in 1808; however, Adair Crawford in 1790 recognized a new mineral (*strontianite*) as differing from other barium minerals (*baryta*). Strontium is found chiefly as *celestite* (SrSO_4) and *strontianite* (SrCO_3). *Celestite* is found in Mexico, Turkey, Iran,

Spain, Algeria, and in the U.K. The U.S. has no active *celestite* mines. The metal can be prepared by electrolysis of the fused chloride mixed with potassium chloride, or is made by reducing strontium oxide with aluminum in a vacuum at a temperature at which strontium distills off. Three allotropic forms of the metal exist, with transition points at 235 and 540 °C. Strontium is softer than calcium and decomposes water more vigorously. It does not absorb nitrogen below 380 °C. It should be kept under mineral oil to prevent oxidation. Freshly cut strontium has a silvery appearance, but rapidly turns a yellowish color with the formation of the oxide. The finely divided metal ignites spontaneously in air. Volatile strontium salts impart a beautiful crimson color to flames, and these salts are used in pyrotechnics and in the production of flares. The major use for strontium at present is in producing glass for color television picture tubes. All color TV and cathode ray tubes sold in the U.S. are required by law to contain strontium in the face plate glass to block x-ray emission. Strontium also improves the brilliance of the glass and the quality of the picture. It has also found use in producing ferrite magnets and in refining zinc. Strontium titanate is an interesting optical material as it has an extremely high refractive index and an optical dispersion greater than that of diamond. It has been used as a gemstone, but it is very soft. It does not occur naturally.

Sulfur — (Sanskrit, *sulvere*; L. *sulphurium*), S. Known to the ancients; referred to in Genesis as *brimstone*. Sulfur is found in meteorites. A dark area near the crater Aristarchus on the moon has been studied by R. W. Wood with ultraviolet light. This study suggests strongly that it is a sulfur deposit. Sulfur occurs native in the vicinity of volcanoes and hot springs. It is widely distributed in nature as *iron pyrites*, *galena*, *sphalerite*, *cinnabar*, *stibnite*, *gypsum*, *Epsom salts*, *celestite*, *barite*, etc. Sulfur is commercially recovered from wells sunk into the salt domes along the Gulf Coast of the U.S. It is obtained from these wells by the Frasch process, which forces heated water into the wells to melt the sulfur, which is then brought to the surface. Sulfur compounds also occur in natural gas and petroleum crudes and must be removed from these products. Formerly this was done chemically, which wasted the sulfur. New processes now permit recovery, and these sources promise to be very important. Large amounts of sulfur are being recovered from Alberta gas fields. Sulfur is a pale yellow, odorless, brittle solid that is insoluble in water but soluble in carbon disulfide. In every state, whether gas, liquid or solid, elemental sulfur occurs in more than one allotropic form or modification; these present a confusing multitude of forms whose relations are not yet fully understood. Amorphous or “plastic” sulfur is obtained by fast cooling of the crystalline form. X-ray studies indicate that amorphous sulfur may have a helical structure with eight atoms per spiral. Crystalline sulfur seems to be made of rings, each containing eight sulfur atoms that fit together to give a normal x-ray pattern. A finely divided form of sulfur, known as *flowers of sulfur*, is obtained by sublimation. Sulfur readily forms sulfides with many elements. Sulfur is a component of black gunpowder, and is used in the vulcanization of natural rubber and as a fungicide. It is also used extensively in

making phosphate fertilizers. A large tonnage is used to produce sulfuric acid, the most important manufactured sulfur compound. It is used in making sulfite paper and other papers, as a fumigant, and in the bleaching of dried fruits. The element is a good electrical insulator. Organic compounds containing sulfur are very important. Calcium sulfate, ammonium sulfate, carbon disulfide, sulfur dioxide, and hydrogen sulfide are but a few of the many other important compounds of sulfur. Sulfur is essential to life. It is a minor constituent of fats, body fluids, and skeletal minerals. Carbon disulfide, hydrogen sulfide, and sulfur dioxide should be handled carefully. Hydrogen sulfide in small concentrations can be metabolized, but in higher concentrations it can quickly cause death by respiratory paralysis. It is insidious in that it quickly deadens the sense of smell. Sulfur dioxide is a dangerous component in atmospheric pollution.

Tantalum — (Gr. *Tantalos*, mythological character, father of *Niobe*), Ta. Discovered in 1802 by Ekeberg, but many chemists thought niobium and tantalum were identical elements until Rose, in 1844, and Marignac, in 1866, showed that niobic and tantallic acids were two different acids. The early investigators only isolated the impure metal. The first relatively pure ductile tantalum was produced by von Bolton in 1903. Tantalum occurs principally in the mineral *columbite-tantalite* (Fe,Mn)(Nb,Ta)₂O₆. Tantalum ores are found in Australia, Brazil, Rwanda, Zimbabwe, Congo-Kinshasa, Nigeria, and Canada. Separation of tantalum from niobium requires several complicated steps. Several methods are used to commercially produce the element, including electrolysis of molten potassium fluorotantalate, reduction of potassium fluorotantalate with sodium, or reacting tantalum carbide with tantalum oxide. Natural tantalum contains two isotopes, one of which is radioactive with a very long half-life. Tantalum is a gray, heavy, and very hard metal. When pure, it is ductile and can be drawn into fine wire, which is used as a filament for evaporating metals such as aluminum. Tantalum is almost completely immune to chemical attack at temperatures below 150 °C, and is attacked only by hydrofluoric acid, acidic solutions containing the fluoride ion, and free sulfur trioxide. Alkaline solutions attack it only slowly. At high temperatures, tantalum becomes much more reactive. The melting point of tantalum is exceeded only by tungsten and rhenium. Tantalum is used to make a variety of alloys with desirable properties such as high-melting point, high strength, good ductility, etc. A tantalum carbide graphite composite material is one of the hardest materials ever made. Tantalum has good “gettering” ability at high temperatures, and tantalum oxide films are stable and have good rectifying and dielectric properties. Tantalum is used to make electrolytic capacitors and vacuum furnace parts, which account for about 60% of its production. The metal is also widely used to fabricate chemical process equipment, nuclear reactors, and aircraft and missile parts. Tantalum is completely immune to body liquids and is a nonirritating metal. It has, therefore, found wide use in making surgical appliances. Tantalum oxide is used to make special glass with a high index of refraction for camera lenses. The metal has many other uses.

Technetium — (Gr. *technetos*, artificial), Tc. Element 43 was predicted on the basis of the periodic table, and was erroneously reported as having been discovered in 1925, at which time it was named *masurium*. The element was actually discovered by Perrier and Segre in Italy in 1937. It was found in a sample of molybdenum that was bombarded by deuterons in the Berkeley cyclotron, and which E. Lawrence sent to these investigators. Technetium was the first element to be produced artificially. Since its discovery, searches for the element in terrestrial materials have been made without success. If it does exist, the concentration must be very small. Technetium has been found in the spectrum of S-, M-, and N-type stars, and its presence in stellar matter is leading to new theories of the production of heavy elements in the stars. ^{97}Tc has a half-life of 2.6×10^6 years. ^{98}Tc has a half-life of 4.2×10^6 years. The isomeric isotope $^{95\text{m}}\text{Tc}$, with a half-life of 61 days, is useful for tracer work, as it produces energetic gamma rays. Technetium metal has been produced in kilogram quantities. The metal was first prepared by passing hydrogen gas at 1100°C over Tc_2S_7 . It is now conveniently prepared by the reduction of ammonium pertechnetate with hydrogen. Technetium is a silvery-gray metal that tarnishes slowly in moist air. The chemistry of technetium is similar to that of rhenium. Technetium dissolves in nitric acid, aqua regia, and concentrated sulfuric acid, but is not soluble in hydrochloric acid of any strength. The element is a remarkable corrosion inhibitor for steel. It is reported that mild carbon steels may be effectively protected by as little as 55 ppm of KTcO_4 in aerated distilled water at temperatures up to 250°C . This corrosion protection is limited to closed systems, since technetium is radioactive and must be confined. ^{99}Tc is a contamination hazard and should be handled in a glove box. The metal is an excellent superconductor at 11 K and below.

Tellurium — (L. *tellus*, earth), Te. Discovered by Muller von Reichenstein in 1782; named by Klaproth, who isolated it in 1798. Tellurium is occasionally found native, but is more often found as the telluride of gold (*calaverite*), and combined with other metals. It is recovered commercially from the anode muds produced during the electrolytic refining of blister copper. The U.S., Canada, Peru, and Japan are the largest producers of the element. Crystalline tellurium has a silvery-white appearance, and when pure exhibits a metallic luster. It is brittle and easily pulverized. Amorphous tellurium is formed by precipitating tellurium from a solution of telluric or tellurous acid. Whether this form is truly amorphous, or made of minute crystals, is open to question. Tellurium is a p-type semiconductor, and shows greater conductivity in certain directions, depending on alignment of the atoms. Its conductivity increases slightly with exposure to light. It can be doped with silver, copper, gold, tin, or other elements. In air, tellurium burns with a greenish-blue flame, forming the dioxide. Molten tellurium corrodes iron, copper, and stainless steel. Tellurium and its compounds are probably toxic and should be handled with care. Workmen exposed to as little as 0.01 mg/m^3 of air, or less, develop "tellurium breath," which has a garlic-like odor. Natural tellurium consists of eight isotopes, two of which are radioactive with very long half-lives. Tellurium improves the machinability of copper and stainless steel,

and its addition to lead decreases the corrosive action of sulfuric acid on lead and improves its strength and hardness. Tellurium catalysts are used in the oxidation of organic compounds and are used in hydrogenation and halogenation reactions. Tellurium is also used in electronic and semiconductor devices and is a basic ingredient in blasting caps, and it is added to cast iron for chill control. Tellurium is used in ceramics. Bismuth telluride has been used in thermoelectric devices.

Tennessine — (*Tennessee*, location of Oak Ridge National Laboratory), Ts. A U.S.-Russian collaboration in 2010 detected Element-117 as a product of the fusion reaction of ^{48}Ca and ^{249}Bk . Confirming experiments were done in 2013. IUPAC approved the name Tennessine for Element-117 in 2016. In the periodic table the element falls in the halogen group, but relativistic effects are predicted to alter its chemical behavior beyond what would be expected from simple extrapolation from the lower halogens. The most stable isotope produced so far, ^{293}Ts , has a half-life of about 22 ms.

Terbium — (*Ytterby*, village in Sweden), Tb. Discovered by Mosander in 1843. Terbium is a member of the lanthanide or "rare earth" group of elements. It is found in *cerite*, *gadolinite*, and other minerals along with other rare earths. It is recovered commercially from *monazite* in which it is present to the extent of 0.03%, from *xenotime*, and from *euxenite*, a complex oxide containing 1% or more of terbium. As with other rare earths, elemental terbium can be produced by reducing the anhydrous chloride or fluoride with calcium metal in a tantalum crucible. Calcium and tantalum impurities can be removed by vacuum remelting. Other methods of isolation are possible. Terbium is reasonably stable in air. It is a silver-gray metal, and is malleable, ductile, and soft enough to be cut with a knife. Two crystal modifications exist, with a transformation temperature of 1289°C . The oxide is a chocolate or dark maroon color. Sodium terbium borate is used as a laser material and emits coherent light at $0.546\text{ }\mu\text{m}$. Terbium is used to dope calcium fluoride, calcium tungstate, and strontium molybdate, used in solid-state devices. The oxide has potential application as an activator for green phosphors. It can be used with ZrO_2 as a crystal stabilizer of fuel cells that operate at elevated temperature. Few other uses have been found. Little is known of the toxicity of terbium. It should be handled with care as with other lanthanide elements.

Thallium — (Gr. *thallos*, a green shoot or twig), Tl. Thallium was discovered spectroscopically in 1861 by Crookes. The element was named after the beautiful green spectral line, which identified the element. The metal was isolated both by Crookes and Lamy in 1862 about the same time. Thallium occurs in *crooksite*, *lorandite*, and *hutchinsonite*. It is also present in *pyrites* and is recovered from the roasting of this ore in connection with the production of sulfuric acid. It is also obtained from the smelting of lead and zinc ores. Extraction is somewhat complex and depends on the source of the thallium. Manganese nodules, found on the ocean floor, contain thallium. When freshly exposed to air, thallium exhibits a metallic luster, but soon develops a bluish-gray tinge, resembling lead in appearance. A heavy oxide builds up on thallium if left in air, and in the presence of water the hydroxide is formed. The metal is very soft and

malleable. It can be cut with a knife. The element and its compounds are toxic and should be handled carefully. Contact of the metal with skin is dangerous, and when melting the metal adequate ventilation should be provided. Thallium is suspected of carcinogenic potential for man. Thallium sulfate has been widely employed as a rodenticide and ant killer. It is odorless and tasteless, giving no warning of its presence. Its use, however, has been prohibited in the U.S. since 1975 as a household insecticide and rodenticide. The electrical conductivity of thallium sulfide changes with exposure to infrared light, and this compound is used in photocells. Thallium bromide-iodide crystals have been used as infrared optical materials. Thallium has been used, with sulfur or selenium and arsenic, to produce low-melting glasses which become fluid between 125 and 150 °C. These glasses have properties at room temperatures similar to ordinary glasses and are said to be durable and insoluble in water. Thallium oxide has been used to produce glasses with a high index of refraction. Thallium has been used in treating ringworm and other skin infections; however, its use has been limited because of the narrow margin between toxicity and therapeutic benefits. A mercury-thallium alloy, which forms a eutectic at 8.5% thallium, freezes at -60 °C, some 20° below the freezing point of mercury.

Thorium — (*Thor*, Scandinavian god of war), Th. Discovered by Berzelius in 1828. Thorium occurs in *thorite* (ThSiO_4) and in *thorianite* ($\text{ThO}_2 + \text{UO}_2$). Large deposits of thorium minerals have been reported in New England and elsewhere, but these have not yet been exploited. Thorium is now thought to be about three times as abundant as uranium and about as abundant as lead or molybdenum. The metal can a source of nuclear power. There is probably more energy available for use from thorium in the minerals of the Earth's crust than from both uranium and fossil fuels. However, any sizable demand for thorium as a nuclear fuel is still in the future. Work has been done in developing thorium cycle converter-reactor systems. Several prototypes, including the HTGR (high-temperature gas-cooled reactor) and MSRE (molten salt converter reactor experiment), have operated. While the HTGR reactors are efficient, they are not expected to become important commercially for many years because of certain operating difficulties. Thorium is recovered commercially from the mineral *monazite*, which contains from 3% to 9% ThO_2 along with rare-earth minerals. Much of the internal heat the Earth produces has been attributed to thorium and uranium. Several methods are available for producing thorium metal: it can be obtained by reducing thorium oxide with calcium, by electrolysis of anhydrous thorium chloride in a fused mixture of sodium and potassium chlorides, by calcium reduction of thorium tetrachloride mixed with anhydrous zinc chloride, and by reduction of thorium tetrachloride with an alkali metal. Thorium was originally assigned a position in Group IV of the periodic table. Because of its atomic weight, valence, etc., it is now considered to be the second member of the *actinide* series of elements. When pure, thorium is a silvery-white metal which is air stable and retains its luster for several months. When contaminated with the oxide, thorium slowly tarnishes in air,

becoming gray and finally black. The physical properties of thorium are greatly influenced by the degree of contamination with the oxide. The purest specimens often contain several tenths of a percent of the oxide. High-purity thorium has been made. Pure thorium is soft, very ductile, and can be cold-rolled, swaged, and drawn. Thorium is dimorphic, changing at 1360 °C from a cubic to a body-centered cubic structure. Thorium oxide has a melting point of 3300 °C, which is the highest of all oxides. Only a few elements, such as tungsten, and a few compounds, such as tantalum carbide, have higher melting points. Thorium is slowly attacked by water, but does not dissolve readily in most common acids, except hydrochloric. Powdered thorium metal is often pyrophoric and should be carefully handled. When heated in air, thorium turnings ignite and burn brilliantly with a white light. A former use of thorium was in the preparation of the Welsbach mantle, used for portable gas lights. These mantles, consisting of thorium oxide with about 1% cerium oxide and other ingredients, glow with a dazzling light when heated in a gas flame. Thorium is an important alloying element in magnesium, imparting high strength and creep resistance at elevated temperatures. Because thorium has a low work function and high electron emission, it is used to coat tungsten wire used in electronic equipment. The oxide is also used to control the grain size of tungsten used for electric lamps; it is also used for high-temperature laboratory crucibles. Glasses containing thorium oxide have a high refractive index and low dispersion. Consequently, they find application in high quality lenses for cameras and scientific instruments. Thorium oxide has also found use as a catalyst in the conversion of ammonia to nitric acid, in petroleum cracking, and in producing sulfuric acid. Its radioactive nature and its handling and disposal problems limit other applications. ^{232}Th is sufficiently radioactive to expose a photographic plate in a few hours. Thorium disintegrates with the production of ^{220}Rn , which is an alpha emitter and presents a radiation hazard. Good ventilation of areas where thorium is stored or handled is therefore essential.

Thulium — (*Thule*, the earliest name for Scandinavia), Tm. Discovered in 1879 by Cleve. Thulium occurs in small quantities along with other rare earths in a number of minerals. It is obtained commercially from *monazite*, which contains about 0.007% of the element. Thulium is the least abundant of the rare-earth elements, but with new sources recently discovered, it is now considered to be about as rare as silver, gold, or cadmium. Ion-exchange and solvent extraction techniques have recently permitted much easier separation of the rare earths, with much lower costs. Thulium can be isolated by reduction of the oxide with lanthanum metal or by calcium reduction of the anhydrous fluoride. The pure metal has a bright, silvery luster. It is reasonably stable in air, but the metal should be protected from moisture in a closed container. The element is silver-gray, soft, malleable, and ductile, and can be cut with a knife. Because of the relatively high price of the metal, thulium has not yet found many practical applications. ^{169}Tm bombarded in a nuclear reactor can be used as a radiation source in portable x-ray equipment. ^{171}Tm is potentially useful as an energy source. Natural thulium

also has possible use in *ferrites* (ceramic magnetic materials) used in microwave equipment. As with other lanthanides, thulium has a low-to-moderate acute toxicity rating. It should be handled with care.

Tin — (Anglo-Saxon, *tin*), Sn (L. *stannum*). Known to the ancients. Tin is found chiefly in *cassiterite* (SnO_2). Most of the world's supply comes from China, Indonesia, Peru, Brazil, and Bolivia. Cornwall was a major source in older periods. The U.S. produces almost none, although occurrences have been found in Alaska and Colorado. Tin is obtained by reducing the ore with coal in a reverberatory furnace. Ordinary tin is a silver-white metal, is malleable, somewhat ductile, and has a highly crystalline structure. Due to the breaking of these crystals, a "tin cry" is heard when a bar is bent. The element has two allotropic forms at normal pressure. On warming, gray, or α -tin, with a cubic structure, changes at 13.2°C into white, or β -tin, the ordinary form of the metal. White tin has a tetragonal structure. When tin is cooled below 13.2°C , it changes slowly from white to gray. This change is affected by impurities such as aluminum and zinc, and can be prevented by small additions of antimony or bismuth. This change from the α to β form is called the tin pest. Tin-lead alloys are used to make organ pipes. There are few if any uses for gray tin. Tin takes a high polish and is used to coat other metals to prevent corrosion or other chemical action. Such tin plate over steel is used in the so-called tin can for preserving food. Alloys of tin are very important. Soft solder, type metal, fusible metal, pewter, bronze, bell metal, Babbitt metal, white metal, die casting alloy, and phosphor bronze are some of the important alloys using tin. Tin resists distilled sea and soft tap water, but is attacked by strong acids, alkalis, and acid salts. Oxygen in solution accelerates the attack. When heated in air, tin forms SnO_2 , which is feebly acid, forming stannate salts with basic oxides. The most important salt is the chloride ($\text{SnCl}_2 \cdot \text{H}_2\text{O}$), which is used as a reducing agent and as a mordant in calico printing. Tin salts sprayed onto glass are used to produce electrically conductive coatings. These have been used for panel lighting and for frost-free windshields. Most window glass is now made by floating molten glass on molten tin (float glass) to produce a flat surface (Pilkington process). Of recent interest is a crystalline tin-niobium alloy that is superconductive at very low temperatures. This promises to be important in the construction of superconductive magnets. Such magnets, made with tin-niobium wire, weigh but a few pounds and produce magnetic fields that are comparable to much larger electromagnets. The small amount of tin found in canned foods is quite harmless. The agreed limit of tin content in U.S. foods is 300 mg/kg. The trialkyl and triaryl tin compounds are used as biocides and must be handled carefully.

Titanium — (L. *Titans*, the first sons of the Earth, myth.), Ti. Discovered by Gregor in 1791; named by Klaproth in 1795. Impure titanium was prepared by Nilson and Pettersson in 1887; however, the pure metal (99.9%) was not made until 1910 by Hunter by heating TiCl_4 with sodium in a steel bomb. Titanium is present in meteorites and in the sun. Rocks obtained during the Apollo 17 lunar mission showed the presence of 12.1% TiO_2 . Analyses of rocks obtained during earlier Apollo

missions show lower percentages. Titanium oxide bands are prominent in the spectra of M-type stars. The element is the ninth most abundant in the crust of the Earth. Titanium is almost always present in igneous rocks and in the sediments derived from them. It occurs in the minerals *rutile*, *ilmenite*, and *sphene*, and is present in titanates and in many iron ores. Deposits of ilmenite and rutile are found in Florida, California, Tennessee, and New York. Australia, Norway, Malaysia, India, and China are also large suppliers of titanium minerals. Titanium is present in the ash of coal, in plants, and in the human body. The metal was a laboratory curiosity until Kroll, in 1946, showed that titanium could be produced commercially by reducing titanium tetrachloride with magnesium. This method is largely used for producing the metal today. The metal can be purified by decomposing the iodide. Titanium, when pure, is a lustrous, white metal. It has a low density, good strength, is easily fabricated, and has excellent corrosion resistance. It is ductile only when it is free of oxygen. The metal burns in air and is the only element that burns in nitrogen. Titanium is resistant to dilute sulfuric and hydrochloric acids, most organic acids, moist chlorine gas, and chloride solutions. The metal is dimorphic. The hexagonal α form changes to the cubic β form very slowly at 882°C . The metal combines with oxygen at red heat, and with chlorine at 550°C . Titanium is important as an alloying agent with aluminum, molybdenum, manganese, iron, and other metals. Alloys of titanium are principally used for aircraft and missiles where lightweight strength and ability to withstand extremes of temperature are important. Titanium is as strong as steel, but 45% lighter. It is 60% heavier than aluminum, but twice as strong. Titanium has potential use in desalination plants for converting sea water into fresh water. The metal has excellent resistance to sea water and is used for propeller shafts, rigging, and other parts of ships exposed to salt water. A titanium anode coated with platinum has been used to provide cathodic protection from corrosion by salt water. Titanium metal is considered to be physiologically inert; however, titanium powder may be a carcinogenic hazard. When pure, titanium dioxide is relatively clear and has an extremely high index of refraction with an optical dispersion higher than diamond. It is produced artificially for use as a gemstone, but it is relatively soft. Star sapphires and rubies exhibit their asterism as a result of the presence of TiO_2 . Titanium dioxide is extensively used for both house paint and artist's paint, as it is permanent and has good covering power. Titanium oxide pigment accounts for the largest use of the element. Titanium paint is an excellent reflector of infrared, and is extensively used in solar observatories where heat causes poor seeing conditions. Titanium tetrachloride is used to iridize glass. This compound fumes strongly in air and has been used to produce smoke screens.

Tungsten — (Swedish, *tung sten*, heavy stone); also known as *wolfram* (from *wolframite*, said to be named from *wolf rahm* or *spumi lupi*, because the ore interfered with the smelting of tin and was supposed to devour the tin), W. In 1779 Peter Woulfe examined the mineral now known as *wolframite* and concluded it must contain a new substance. Scheele, in 1781, found that a new acid

could be made from *tungsten* (a name first applied about 1758 to a mineral now known as *scheelite*). Scheele and Berman suggested the possibility of obtaining a new metal by reducing this acid. The de Elhuyar brothers found an acid in *wolframite* in 1783 that was identical to the acid of *tungsten* (tungstic acid) of Scheele, and in that year they succeeded in obtaining the element by reduction of this acid with charcoal. Tungsten occurs in *wolframite*, $(\text{Fe},\text{Mn})\text{WO}_4$; *scheelite*, CaWO_4 ; *huebnerite*, MnWO_4 ; and *ferberite*, FeWO_4 . Important deposits of tungsten occur in California, Colorado, Bolivia, Russia, and Portugal. China is reported to have about 75% of the world's tungsten resources. The metal is obtained commercially by reducing tungsten oxide with hydrogen or carbon. Pure tungsten is a steel-gray to tin-white metal. Very pure tungsten can be cut with a hacksaw, and can be forged, spun, drawn, and extruded. The impure metal is brittle and can be worked only with difficulty. Tungsten has the highest melting point of all metals, and at temperatures over 1650 °C has the highest tensile strength. The metal oxidizes in air and must be protected at elevated temperatures. It has excellent corrosion resistance and is attacked only slightly by most mineral acids. The thermal expansion is about the same as borosilicate glass, which makes the metal useful for glass-to-metal seals. Tungsten and its alloys are used extensively for filaments for electric light bulbs and for metal evaporation work; for electrical contact points for automobile distributors; x-ray targets; windings and heating elements for electrical furnaces; and for numerous spacecraft and high-temperature applications. High-speed tool steels, Hastelloy, Stellite, and many other alloys contain tungsten. Tungsten carbide is of great importance to the metal-working, mining, and petroleum industries. Calcium and magnesium tungstates are widely used in fluorescent lighting; other salts of tungsten are used in the chemical and tanning industries. Tungsten disulfide is a dry, high-temperature lubricant, stable to 500 °C. Tungsten bronzes and other tungsten compounds are used in paints. Zirconium tungstate has found recent applications (see under Zirconium).

Uranium — (Planet *Uranus*), U. Yellow-colored glass, containing more than 1% uranium oxide and dating back to 79 A.D., has been found near Naples, Italy. Klaproth recognized an unknown element in *pitchblende* and attempted to isolate the metal in 1789. The metal apparently was first isolated in 1841 by Peligot, who reduced the anhydrous chloride with potassium. Uranium is not as rare as it was once thought. It is now considered to be more plentiful than mercury, antimony, silver, or cadmium, and is about as abundant as molybdenum or arsenic. It occurs in numerous minerals such as *pitchblende*, *uraninite*, *carnotite*, *autunite*, *uranophane*, *davidite*, and *tobernite*. It is also found in *phosphate rock*, *lignite*, *monazite sands*, and can be recovered commercially from these sources. Large deposits of uranium ore occur in Utah, Colorado, New Mexico, Canada, and elsewhere. Uranium can be made by reducing uranium halides with alkali or alkaline earth metals or by reducing uranium oxides by calcium, aluminum, or carbon at high temperatures. The metal can also be produced by electrolysis of KUF_5 or UF_4 , dissolved in a molten mixture of CaCl_2 and NaCl . High-purity uranium can be prepared

by the thermal decomposition of uranium halides on a hot filament. Uranium metal exhibits three crystallographic modifications α , β , and γ , with transitions at 669 °C and 776 °C. Uranium is a heavy, silvery-white metal that is pyrophoric when finely divided. It is a little softer than steel, and is attacked by cold water in a finely divided state. It is malleable, ductile, and slightly paramagnetic. In air, the metal becomes coated with a layer of oxide. Acids dissolve the metal, but it is unaffected by alkalis. Natural uranium is sufficiently radioactive to expose a photographic plate in an hour or so. Much of the internal heat of the Earth is thought to be attributable to the presence of uranium and thorium. ^{238}U , with a half-life of 4.46×10^9 years, has been used to estimate the age of igneous rocks. The origin of uranium, the highest member of the naturally occurring elements — except perhaps for traces of neptunium or plutonium — is not clearly understood, although it has been suggested that uranium might be a decay product of elements of higher atomic weight, which may have once been present on Earth or elsewhere in the universe. These original elements may have been formed as a result of the primordial big bang, in a supernova, or in some other stellar processes. The fact that recent studies show that most transuranic elements are extremely rare with very short half-lives indicates that it may be necessary to find some alternative explanation for the very large quantities of radioactive uranium we find on Earth. Studies of meteorites from other parts of the solar system show a relatively low radioactive content, compared to terrestrial rocks. Uranium is of great importance as a nuclear fuel. ^{238}U can be converted into fissionable plutonium in breeder reactors, where it is possible to produce more new fissionable material than the fissionable material used in maintaining the chain reaction. ^{235}U is of even greater importance, for it is the key to the utilization of uranium. ^{235}U , while occurring in natural uranium to the extent of only 0.72%, is so fissionable with slow neutrons that a self-sustaining fission chain reaction can be made to occur in a reactor constructed from natural uranium and a suitable moderator, such as heavy water or graphite, alone. ^{235}U can be concentrated by gaseous diffusion and other physical processes and used directly as a nuclear fuel, instead of natural uranium, or used as an explosive. Natural uranium, slightly enriched with ^{235}U by a small percentage, is used to fuel nuclear power reactors for the generation of electricity. One pound of completely fissioned uranium has the fuel value of over 1500 tons of coal. However, there are serious problems with nuclear waste disposal that have not been resolved. Depleted uranium has been used for inertial guidance devices, gyrocompasses, counterweights for aircraft control surfaces, ballast for missile reentry vehicles, and as a shielding material for tanks, etc. Concerns, however, have been raised over its low radioactive properties. Uranium metal is used for x-ray targets for production of high-energy x-rays. The nitrate has been used as photographic toner, and the acetate is used in analytical chemistry. Crystals of uranium nitrate are triboluminescent. Uranium salts have also been used for producing yellow "vaseline" glass and glazes. Uranium and its compounds are highly toxic, both from a chemical and

radiological standpoint. Finely divided uranium metal, being pyrophoric, presents a fire hazard.

Vanadium — (Scandinavian goddess, *Vanadis*), V. Vanadium was first discovered by del Rio in 1801. Unfortunately, a French chemist incorrectly declared that del Rio's new element was only impure chromium; del Rio thought himself to be mistaken and accepted the French chemist's statement. The element was rediscovered in 1830 by Sefstrom, who named the element in honor of the Scandinavian goddess *Vanadis* because of its beautiful multicolored compounds. It was isolated in nearly pure form by Roscoe, in 1867, who reduced the chloride with hydrogen. Vanadium of 99.3% to 99.8% purity was not produced until 1927. Vanadium is found in about 65 different minerals among which *carnotite*, *roscoelite*, *vanadinite*, and *patronite* are important sources of the metal. Vanadium is also found in phosphate rock and certain iron ores, and is present in some crude oils in the form of organic complexes. It is also found in small percentages in meteorites. Commercial production from petroleum ash holds promise as an important source of the element. China, South Africa, and Russia supply much of the world's vanadium ores. High-purity ductile vanadium can be obtained by reduction of vanadium trichloride with magnesium or with magnesium-sodium mixtures. Much of the vanadium metal being produced is now made by calcium reduction of V_2O_5 in a pressure vessel, an adaptation of a process developed by McKechnie and Seybolt. Pure vanadium is a bright white metal, and is soft and ductile. It has good corrosion resistance to alkalis, sulfuric and hydrochloric acids, and salt water, but the metal oxidizes readily above 660 °C. The metal has good structural strength and a low-fission neutron cross section, making it useful in nuclear applications. Vanadium is used in producing rust-resistant spring and high-speed tool steels. It is an important carbide stabilizer in making steels. About 80% of the vanadium now produced is used as ferrovanadium or as a steel additive. Vanadium foil is used as a bonding agent in cladding titanium to steel. Vanadium pentoxide is used in ceramics and as a catalyst. Vanadium and its compounds are toxic and should be handled with care. Ductile vanadium is commercially available.

Xenon — (Gr. *xenon*, stranger), Xe. Discovered by Ramsay and Travers in 1898 in the residue left after evaporating liquid air components. Xenon is a member of the so-called noble or "inert" gases. It is present in the atmosphere at a concentration of 0.0114%. Xenon is present in the Martian atmosphere to the extent of 0.08 ppm. The element is found in the gases evolved from certain mineral springs, and is commercially obtained by extraction from liquid air. Before 1962, it had generally been assumed that xenon and other noble gases were unable to form compounds. However, it is now known that xenon, as well as other members of the zero valence elements, do form compounds. Among the compounds of xenon now reported are the difluoride, tetrafluoride, and hexafluoride; xenon hydrate, sodium perxenate, xenon deuterate, and $XePtF_6$ and $XeRhF_6$. Xenon trioxide, which is highly explosive, has been prepared. More than 80 xenon compounds have been made with xenon chemically bonded to fluorine and oxygen. Some xenon compounds are colored. Metallic xenon has also been

produced, using several hundred kilobars of pressure. Xenon in a vacuum tube produces a beautiful blue glow when excited by an electrical discharge. The gas is used in making stroboscopic lamps, bactericidal lamps, and lamps used to excite ruby lasers. Xenon is used in the nuclear energy field in bubble chambers, probes, and other applications where its high molecular weight is of value. The perxenates are used in analytical chemistry as oxidizing agents. ^{133}Xe and ^{135}Xe are produced by neutron irradiation in air-cooled nuclear reactors. ^{133}Xe has useful applications as a radioisotope. Xenon is not toxic, but its compounds are highly toxic because of their strong oxidizing characteristics.

Ytterbium — (*Ytterby*, village in Sweden), Yb. Marignac in 1878 discovered a new component, which he called *ytterbia*, in the Earth then known as *erbia*. In 1907, Urbain separated *ytterbia* into two components, which he called *neoytterbia* and *lutecia*. The elements in these earths are now known as *ytterbium* and *lutetium*, respectively. These elements are identical with *aldebaranium* and *cassiopeium*, discovered independently and at about the same time by von Welsbach. Ytterbium occurs along with other rare earths in a number of rare minerals. It is commercially recovered principally from *monazite sand*, which contains about 0.03%. Ion-exchange and solvent extraction techniques developed in recent years have greatly simplified the separation of the rare earths from one another. The element was first prepared by Klemm and Bonner in 1937 by reducing ytterbium trichloride with potassium. Their metal was mixed, however, with KCl. Daane, Dennison, and Spedding prepared a much purer form in 1953 from which the chemical and physical properties of the element could be determined. Ytterbium has a bright silvery luster, is soft, malleable, and quite ductile. While the element is fairly stable, it should be kept in closed containers to protect it from air and moisture. Ytterbium is readily attacked and dissolved by dilute and concentrated mineral acids and reacts slowly with water. Ytterbium has three allotropic forms with transformation points at 3° and 795 °C. The beta form is a room-temperature, face-centered, cubic modification, while the high-temperature gamma form is a body-centered cubic form. Another body-centered cubic phase has recently been found to be stable at high pressures at room temperatures. The beta form ordinarily has metallic-type conductivity, but becomes a semiconductor when the pressure is increased above 16,000 atm. The electrical resistance increases tenfold as the pressure is increased to 39,000 atm and drops to about 80% of its standard temperature-pressure resistivity at a pressure of 40,000 atm. Ytterbium metal has possible use in improving the grain refinement, strength, and other mechanical properties of stainless steel. Few other uses have been found. Ytterbium has a low acute toxicity rating.

Yttrium — (*Ytterby*, village in Sweden near Vauxholm), Y. *Yttria*, which is an earth containing yttrium, was discovered by Gadolin in 1794. *Ytterby* is the site of a quarry which yielded many unusually minerals containing rare earths and other elements. This small town, near Stockholm, bears the honor of giving names to *erbitium*, *terbitium*, and *ytterbitium* as well as *yttrium*. In 1843 Mosander showed that *yttria* could be resolved into the oxides (or earths) of three elements. The name *yttria* was reserved for the

most basic one; the others were named *erbia* and *terbia*. Yttrium occurs in nearly all of the rare-earth minerals. Analysis of lunar rock samples obtained during the Apollo missions show a relatively high yttrium content. It is recovered commercially from *monazite sand*, which contains about 3%, and from *bastnasite*, which contains about 0.2%. Wohler obtained the impure element in 1828 by reduction of the anhydrous chloride with potassium. The metal is now produced commercially by reduction of the fluoride with calcium metal. It can also be prepared by other techniques. Yttrium has a silver-metallic luster and is relatively stable in air. Turnings of the metal, however, ignite in air if their temperature exceeds 400 °C, and finely divided yttrium is very unstable in air. Yttrium oxide is one of the most important compounds of yttrium and accounts for the largest use. At one time it was used in making YVO_4 europium, and Y_2O_3 europium phosphors to give the red color in color television tubes. Yttrium oxide also is used to produce yttrium iron garnets, which are very effective microwave filters. Yttrium iron, aluminum, and gadolinium garnets, with formulas such as $Y_3Fe_5O_{12}$ and $Y_3Al_5O_{12}$, have interesting magnetic properties. Yttrium iron garnet is also exceptionally efficient as both a transmitter and transducer of acoustic energy. These yttrium garnets have many uses in the electronics industry. Yttrium aluminum garnet, with a hardness of 8.5, is also finding use as a gemstone (simulated diamond). Small amounts of yttrium (0.1% to 0.2%) can be used to reduce the grain size in chromium, molybdenum, zirconium, and titanium, and to increase strength of aluminum and magnesium alloys. Alloys with other useful properties can be obtained by using yttrium as an additive. The metal can be used as a deoxidizer for vanadium and other nonferrous metals. Yttrium has been considered for use as a nodulizer for producing nodular cast iron, in which the graphite forms compact nodules instead of the usual flakes. Such iron has increased ductility. Yttrium is also finding application in laser systems and as a catalyst for ethylene polymerization. It also has potential use in ceramic and glass formulas, as the oxide has a high-melting point and imparts shock resistance and low expansion characteristics to glass.

Zinc — (Ger. *Zink*, of obscure origin), Zn. Centuries before zinc was recognized as a distinct element, zinc ores were used for making brass. Tubal-Cain, seven generations from Adam, is mentioned as being an “instructor in every artifice in brass and iron.” An alloy containing 87% zinc has been found in prehistoric ruins in Transylvania. Metallic zinc was produced in the 13th century A.D. in India by reducing calamine with organic substances such as wool. The metal was rediscovered in Europe by Marggraf in 1746, who showed that it could be obtained by reducing *calamine* with charcoal. The principal ores of zinc are *sphalerite* or *blende* (sulfide), *smithsonite* (carbonate), *calamine* (silicate), and *franklinite* (zinc, manganese, iron oxide). Canada, Japan, Belgium, Germany, and the Netherlands are suppliers of zinc ores. Zinc is also mined in Alaska, Tennessee, Missouri, and elsewhere in the U.S. Zinc can be obtained by roasting its ores to form the oxide and by reduction of the oxide with coal or carbon, with subsequent distillation of the metal. Other methods of extraction are possible.

Zinc is a bluish-white, lustrous metal. It is brittle at ordinary temperatures but malleable at 100 to 150 °C. It is a fair conductor of electricity, and burns in air at high red heat with evolution of white clouds of the oxide. The metal is employed to form numerous alloys with other metals. Brass, nickel silver, typewriter metal, commercial bronze, spring brass, German silver, soft solder, and aluminum solder are some of the more important alloys. Large quantities of zinc are used to produce die castings, used extensively by the automotive, electrical, and hardware industries. An alloy called *Prestal*, consisting of 78% zinc and 22% aluminum, is reported to be almost as strong as steel but as easy to mold as plastic. Zinc is also extensively used to galvanize other metals such as iron to prevent corrosion. Neither zinc nor zirconium is ferromagnetic; but $ZrZn_2$ exhibits ferromagnetism at temperatures below 35 K. Zinc oxide is a unique and very useful material to modern civilization. It is widely used in the manufacture of paints, rubber products, cosmetics, pharmaceuticals, floor coverings, plastics, printing inks, soap, storage batteries, textiles, electrical equipment, and other products. It has unusual electrical, thermal, optical, and solid-state properties that have not yet been fully investigated. Lithopone, a mixture of zinc sulfide and barium sulfate, is an important pigment. Zinc sulfide is used in making luminous dials and fluorescent lights. The chloride and chromate are also important compounds. Zinc is an essential element in the growth of human beings and animals. Tests show that zinc-deficient animals require 50% more food to gain the same weight as an animal supplied with sufficient zinc. Zinc is not considered to be toxic, but when freshly formed ZnO is inhaled a disorder known as the *oxide shakes* or *zinc chills* sometimes occurs. It is recommended that where zinc oxide is encountered good ventilation be provided.

Zirconium — (Syriac, *zargun*, color of gold), Zr. The name *zircon* may have originated from the Syriac word *zargono*, which describes the color of certain gemstones now known as *zircon*, *jargon*, *hyacinth*, *jacinth*, or *ligure*. This mineral, or its variations, is mentioned in biblical writings. These minerals were not known to contain this element until Klaproth, in 1789, analyzed a *jargon* from Sri Lanka and found a new earth, which Werner named zircon (*silex zirconius*), and Klaproth called *Zirkonerde* (*zirconia*). The impure metal was first isolated by Berzelius in 1824 by heating a mixture of potassium and potassium zirconium fluoride in a small iron tube. Pure zirconium was first prepared in 1914. Very pure zirconium was first produced in 1925 by van Arkel and de Boer by an iodide decomposition process they developed. Zirconium is found in abundance in S-type stars, and has been identified in the sun and meteorites. Analyses of lunar rock samples obtained during the various Apollo missions to the moon show a surprisingly high zirconium oxide content, compared with terrestrial rocks. *Zircon*, $ZrSiO_4$, the principal ore, is found in deposits in Florida, South Carolina, Australia, South Africa, and elsewhere. *Baddeleyite*, found in Brazil, is an important zirconium mineral. It is principally pure ZrO_2 in crystalline form having a hafnium content of about 1%. Zirconium also occurs in some 30 other recognized mineral species. Zirconium is produced commercially by reduction of

the chloride with magnesium (the Kroll Process), and by other methods. It is a grayish-white lustrous metal. When finely divided, the metal may ignite spontaneously in air, especially at elevated temperatures. The solid metal is much more difficult to ignite. The inherent toxicity of zirconium compounds is low. Hafnium is invariably found in zirconium ores, and the separation is difficult. Commercial-grade zirconium contains from 1% to 3% hafnium. Zirconium has a low absorption cross section for neutrons, and is therefore used for nuclear energy applications, such as for cladding fuel elements. Commercial nuclear power generation now takes more than 90% of zirconium metal production. Reactor-grade zirconium is essentially free of hafnium. *Zircaloy* is an important alloy developed specifically for nuclear applications. Zirconium is exceptionally resistant to corrosion by many common acids and alkalis, by sea water, and by other agents. It is used extensively by the chemical industry where corrosive agents are employed. Zirconium is used as a getter in vacuum tubes, as an alloying agent in steel, in surgical

appliances, photoflash bulbs, explosive primers, rayon spinnerets, lamp filaments, etc. It is used in poison ivy lotions in the form of the carbonate as it combines with *urushiol*. With niobium, zirconium is superconductive at low temperatures and is used to make superconductive magnets. Alloyed with zinc, zirconium becomes magnetic at temperatures below 35 K. Zirconium oxide has a high index of refraction and is used as a gem material. The impure oxide, zirconia, is used for laboratory crucibles that will withstand heat shock, for linings of metallurgical furnaces, and by the glass and ceramic industries as a refractory material. Its use as a refractory material accounts for a large share of all zirconium consumed. Zirconium tungstate is an unusual material that shrinks, rather than expands, when heated. A few other compounds are known to possess this property, but they tend to shrink in one direction, while they stretch out in others in order to maintain an overall volume. Zirconium tungstate shrinks in all directions over a wide temperature range of from near absolute zero to +777 °C.

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STANDARD ATOMIC WEIGHTS

This table of atomic weights includes the changes made through 2018 by the International Union of Pure and Applied Chemistry (IUPAC) Commission on Isotopic Abundances and Atomic Weights (Refs. 1,5,6,7,8,9).

IUPAC made a significant policy change in 2009 (Refs. 2-4). Each atomic weight had previously been given as a single value with an uncertainty that took into account both the measurement uncertainty and the variation in isotopic abundance in samples of the element from different terrestrial sources. For a variety of reasons (Ref. 3), this fails to give complete information on the natural variability in isotopic abundance of several elements. Therefore, beginning in 2009 the recommendations expressed the atomic weights of several elements as intervals rather than single numbers plus uncertainties. The symbol for these intervals is $[a, b]$, where a is the lower bound of values found in normal materials and b the upper bound. For the other elements in the table, a single recommended atomic weight value is given; the number in parentheses following the value gives the uncertainty in the last digit.

Table 1 gives the atomic weights of the elements listed in alphabetical order by name. Table 2 gives reference atomic weights for the 11 elements whose entries in Table 1 are intervals rather than

single numbers. These conventional reference values are suggested for use on samples of unspecified origin and for calculation of molecular weights in tables intended to be broadly applicable. They have been selected such that most or all natural terrestrial atomic-weight variation is covered in an interval of plus or minus one in the last digit. It should be emphasized that the conventional values are not simply midpoints of the intervals, but rather represent the best judgment of the data evaluators.

References

1. Wieser, M. E., et al., *Pure Appl. Chem.* 85, 1047, 2013.
2. Wieser, M. E., and Coplen, T. D., *Pure Appl. Chem.* 83, 359, 2011.
3. Coplen, T. B., and Holden, N. E., *Chemistry International*, 33, 2, p. 10, 2011.
4. Berglund, M., and Wieser, M. E., *Pure Appl. Chem.* 83, 397, 2011.
5. *Chemistry International*, 35, 6, p. 17, 2013; <www.ciaaw.org>.
6. *Chemistry International*, 37, 5-6, p. 26, 2015.
7. Meija, J., et al., *Pure Appl. Chem.* 88, 265, 2016.
8. Possolo, A., van der Veen, A. M. H., Meija, J., and Hibbert, B., Interpreting and propagating the uncertainty of the standard atomic weights (IUPAC Technical Report), *Pure Appl. Chem.*, 90, 395–424, 2018, DOI: <https://doi.org/10.1515/pac-2016-0402>.
9. See also <www.ciaaw.org>.

TABLE 1. Standard Atomic Weights 2016

Element	Symbol	Atomic number	Atomic weight	Element	Symbol	Atomic number	Atomic weight
Actinium ^u	Ac	89		Europium ^s	Eu	63	151.964(1)
Aluminum	Al	13	26.9815384(3)	Fermium ^u	Fm	100	
Americium ^u	Am	95		Flerovium ^u	Fl	114	
Antimony ^s	Sb	51	121.760(1)	Fluorine	F	9	18.998403163(6)
Argon ^{s, r}	Ar	18	[39.9792, 39.963]	Francium ^u	Fr	87	
Arsenic	As	33	74.921595(6)	Gadolinium ^s	Gd	64	157.25(3)
Astatine ^u	At	85		Gallium	Ga	31	69.723(1)
Barium	Ba	56	137.327(7)	Germanium	Ge	32	72.630(8)
Berkelium ^u	Bk	97		Gold	Au	79	196.966570(4)
Beryllium	Be	4	9.0121831(5)	Hafnium	Hf	72	178.49(2)
Bismuth ^u	Bi	83	208.98040(1)	Hassium ^u	Hs	108	
Bohrium ^u	Bh	107		Helium ^{s, r}	He	2	4.002602(2)
Boron ^{m, *}	B	5	[10.806, 10.821]	Holmium	Ho	67	164.930328(7)
Bromine ^s	Br	35	[79.901, 79.907]	Hydrogen ^{m, *}	H	1	[1.00784, 1.00811]
Cadmium ^s	Cd	48	112.414(4)	Indium	In	49	114.818(1)
Calcium ^s	Ca	20	40.078(4)	Iodine	I	53	126.90447(3)
Californium ^u	Cf	98		Iridium	Ir	77	192.217(2)
Carbon [*]	C	6	[12.0096, 12.0116]	Iron	Fe	26	55.845(2)
Cerium ^s	Ce	58	140.116(1)	Krypton ^{s, m}	Kr	36	83.798(2)
Cesium ^s	Cs	55	132.90545196(6)	Lanthanum ^s	La	57	138.90547(7)
Chlorine ^{m, *}	Cl	17	[35.446, 35.457]	Lawrencium ^u	Lr	103	
Chromium	Cr	24	51.9961(6)	Lead ^{s, r}	Pb	82	207.2(1)
Cobalt	Co	27	58.933194(3)	Lithium ^{m, *}	Li	3	[6.938, 6.997]
Copernicium ^u	Cn	112		Livermorium ^u	Lv	116	
Copper ^r	Cu	29	63.546(3)	Lutetium ^s	Lu	71	174.9668(1)
Curium ^u	Cm	96		Magnesium [*]	Mg	12	[24.304, 24.307]
Darmstadtium ^u	Ds	110		Manganese	Mn	25	54.938043(2)
Dubnium ^u	Db	105		Meitnerium ^u	Mt	109	
Dysprosium ^s	Dy	66	162.500(1)	Mendelevium ^u	Md	101	
Einsteinium ^u	Es	99		Mercury	Hg	80	200.592(3)
Erbium ^s	Er	68	167.259(3)	Molybdenum ^s	Mo	42	95.95(1)

Element	Symbol	Atomic number	Atomic weight
Moscovium ^u	Mc	115	
Neodymium [§]	Nd	60	144.242(3)
Neon ^{§, m}	Ne	10	20.1797(6)
Neptunium ^u	Np	93	
Nickel	Ni	28	58.6934(4)
Nihonium ^u	Nh	113	
Niobium	Nb	41	92.90637(1)
Nitrogen [*]	N	7	[14.00643, 14.00728]
Nobelium ^u	No	102	
Oganesson ^u	Og	118	
Osmium [§]	Os	76	190.23(3)
Oxygen [*]	O	8	[15.99903, 15.99977]
Palladium [§]	Pd	46	106.42(1)
Phosphorus	P	15	30.973761998(5)
Platinum	Pt	78	195.084(9)
Plutonium ^u	Pu	94	
Polonium ^u	Po	84	
Potassium [§]	K	19	39.0983(1)
Praseodymium	Pr	59	140.90766(1)
Promethium ^u	Pm	61	
Protactinium ^z	Pa	91	231.03588(1)
Radium ^u	Ra	88	
Radon ^u	Rn	86	
Rhenium	Re	75	186.207(1)
Rhodium	Rh	45	102.90549(2)
Roentgenium ^u	Rg	111	
Rubidium [§]	Rb	37	85.4678(3)
Ruthenium [§]	Ru	44	101.07(2)
Rutherfordium ^u	Rf	104	
Samarium [§]	Sm	62	150.36(2)
Scandium	Sc	21	44.955908(5)
Seaborgium ^u	Sg	106	
Selenium	Se	34	78.971(8)
Silicon [*]	Si	14	[28.084, 28.086]

Element	Symbol	Atomic number	Atomic weight
Silver [§]	Ag	47	107.8682(2)
Sodium	Na	11	22.98976928(2)
Strontium ^{§, r}	Sr	38	87.62(1)
Sulfur [*]	S	16	[32.059, 32.076]
Tantalum	Ta	73	180.94788(2)
Technetium ^u	Tc	43	
Tellurium [§]	Te	52	127.60(3)
Tennessine ^u	Ts	117	
Terbium	Tb	65	158.925354(8)
Thallium [*]	Tl	81	[204.382, 204.385]
Thorium ^{§, u}	Th	90	232.0377(4)
Thulium	Tm	69	168.934218(6)
Tin [§]	Sn	50	118.710(7)
Titanium	Ti	22	47.867(1)
Tungsten	W	74	183.84(1)
Uranium ^{§, m, u}	U	92	238.02891(3)
Vanadium	V	23	50.9415(1)
Xenon ^{§, m}	Xe	54	131.293(6)
Ytterbium [§]	Yb	70	173.045(10)
Yttrium	Y	39	88.90584(1)
Zinc ^r	Zn	30	65.38(2)
Zirconium [§]	Zr	40	91.224(2)

[§] Geological specimens are known in which the element has an isotopic composition outside the limits for the normal material. The difference between the atomic weight of the element in such specimens and that given in the table may exceed the stated uncertainty.

^m Modified isotopic compositions may be found in commercially available material because the material has been subjected to an undisclosed or inadvertent isotopic fractionation. Substantial deviations in atomic weight of the element from that given in the table can occur.

^r Range in isotopic composition of normal terrestrial material prevents a more precise atomic weight being given; the tabulated value and uncertainty should be applicable to any normal material.

^u Element has no stable isotopes. See "Table of the Isotopes" in Section 11 for individual isotopic masses. However, four such elements (Bi, Th, Pa, and U) do have a characteristic terrestrial isotopic composition, and for these elements standard atomic weights are tabulated.

^{*} See Table 2.

TABLE 2. Conventional Atomic Weights 2016

Element	Symbol	Atomic number	Reference atomic weight ^a
Boron	B	5	10.81
Bromine	Br	35	79.904
Carbon	C	6	12.011
Chlorine	Cl	17	35.45
Hydrogen	H	1	1.008
Lithium	Li	3	6.94
Magnesium	Mg	12	24.305
Nitrogen	N	7	14.007
Oxygen	O	8	15.999
Silicon	Si	14	28.085
Sulfur	S	16	32.06
Thallium	Tl	81	204.38

^a For users needing an atomic-weight value for an unspecified sample, such as for trade or commerce, see text.