François Cardarelli

Materials Handbook

A Concise Desktop Reference

2nd Edition

Springer

By the same author

Encyclopaedia of Scientific Units, Weight and Measures. Their SI Equivalences and Origin
Springer, New York, London (2005), xxiv, 848 pages
ISBN 978-1-85233-682-0

Materials Handbook: A Concise Desktop Reference
Springer, London, New York (2000), xi, 595 pages
ISBN 978-1-85233-168-9
(Out of print)

Scientific Unit Conversion. A Practical Guide to Metrication, 2nd Edition
Springer, London, New York (1999), xvi, 488 pages
ISBN 978-1-85233-043-9
(Out of print)

Scientific Unit Conversion: A Practical Guide to Metrication
Springer, London, Heidelberg (1997), xvi, 456 pages
ISBN 978-3-540-76022-1
(Out of print)

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Member of ACS, AIChE, ASM, ECS, MAC, MSA, OCQ, SFC and TMS

ISBN 978-1-84628-668-1 e-ISBN 978-1-84628-669-8

DOI 10.1007/978-1-84628-669-8

British Library Cataloguing in Publication Data
Cardarelli, Francois, 1966-
Materials handbook : a concise desktop reference. - 2nd ed.
1. Materials - Handbooks, manuals, etc.
I. Title
620.1'1
ISBN-13: 9781846286681

Library of Congress Control Number: #########

Cover design: eStudio Calamar S.L., Girona, Spain

Printed on acid-free paper

9 8 7 6 5 4 3 2 1

springer.com

A Background Data for the Chemical Elements

A.1 Periodic Chart of the Elements

See Figure A.1, page 1182.

A.2 Historical Names of the Chemical Elements

See Table A.1, page 1183.

A.3 UNS Standard Alphabetical Designation

The ***Unified Numbering System*** (UNS) is the accepted alloy designation system in North America and Worldwide for commercially available metals and alloys[1]. The UNS is managed jointly by the *American Society for Testing and Materials* (ASTM) and the *Society of Automotive Engineers* (SAE). The standard code designation consists of five digits following the prefix letter identifying the alloy's family. Generally, UNS designations are simply expansions of the former designations (i.e., AISI, AA, CDA, etc.).

See Table A.2, page 1184.

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[1] Society of Automotive Engineers (SAE) Metals and Alloys in the Unified Numbering System, 7th. ed. ASTM/SAE (1998).

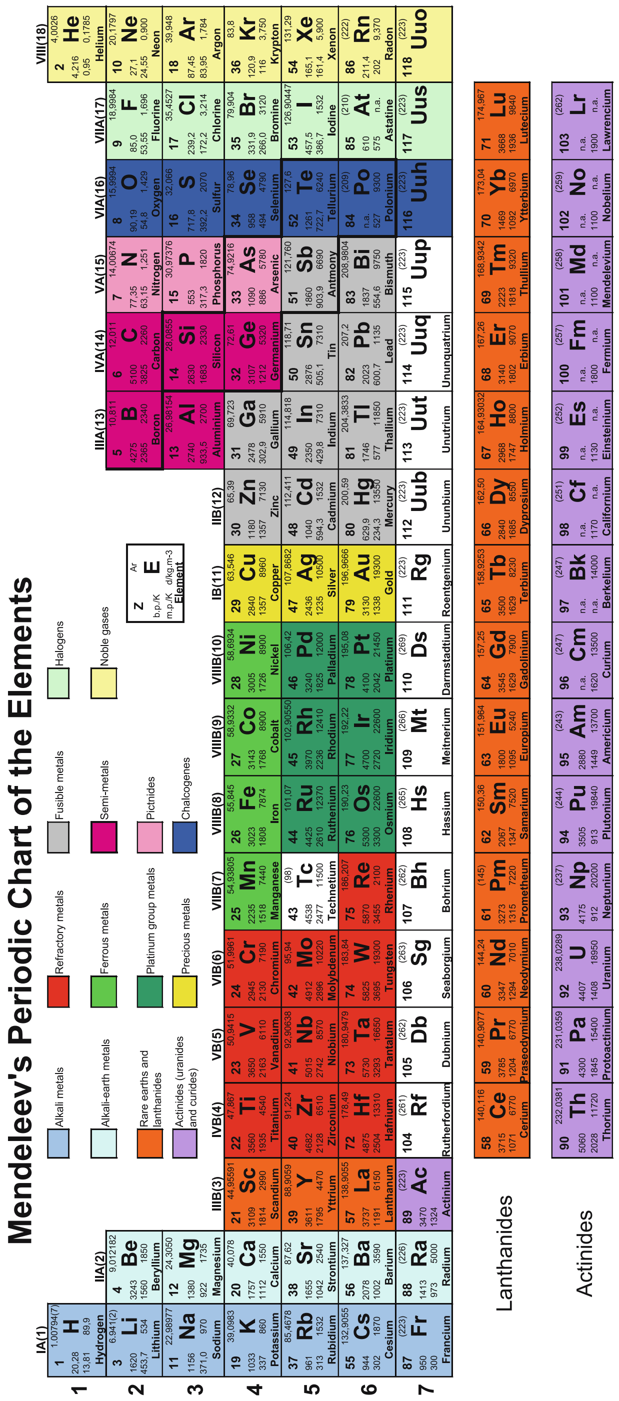

Figure A.1. Mendeleev's Periodic Chart

Table A.1. Obsolete and historical names of the chemical elements

Obsolete name (symbol)	IUPAC name
Actinon (An)	Radon-219
Alabamine	Astatine
Aluminum	Aluminium
Argentum	Silver
Arsenicum	Arsenic
Aurum	Gold
Azote (Az)	Nitrogen
Caesium	Cesium
Cassiopeium	Lutetium
Celtium (Ct)	Hafnium
Columbium (Cb)	Niobium
Cuprum	Copper
Didynium (Dm)	Neodymium + praseodymium
Ekaaluminium	Gallium
Ekacaesium	Francium
Ekasilicon	Germanium
Emanation (Em)	Radon
Erythronium	Vanadium
Ferrum	Iron
Glucinium (Gl)	Beryllium
Hydrargyrum	Mercury
Illinium (Il)	Promethium
Kalium	Potassium
Masurium (Ma)	Technetium
Mischmetal	Cerium impure
Natrium	Sodium
Niton	Radon-222
Panchromium	Vanadium
Plumbum	Lead
Stannum	Tin
Stibium	Antimony
Sulfur	Sulphur
Thoron (Tn)	Radon-220
Virginium (Vi)	Francium
Wolfram	Tungsten

Table A.2. UNS metals and alloys alphabetical designation

UNS Designation	Description
AXXXXX	Aluminum and aluminum alloys
CXXXXX	Copper and copper alloys
DXXXXX	Specified-mechanical-properties steels
EXXXXX	Rare earth and rare earth like metals and alloys
FXXXXX	Cast irons and cast steels
GXXXXX	AISI and SAE carbon and alloy steels
HXXXXX	AISI and SAE H-steels
JXXXXX	Cast steels
KXXXXX	Miscellaneous steels and ferrous alloys
LXXXXX	Low melting metals and alloys
MXXXXX	Miscellaneous nonferrous metals and alloys
NXXXXX	Nickel and nickel alloys
PXXXXX	Precious metals and alloys
RXXXXX	Reactive and refractory metals and alloys
SXXXXX	Heat and corrosion resistant stainless steels
TXXXXX	Tool steels, wrought, and cast
WXXXXX	Welding filler metals
ZXXXXX	Zinc and zinc alloys

A.4 Names of Transfermium Elements 101–110

The *American Chemical Society* (ACS) has adopted names listed in Table A.3 for elements 101–110. These names were adopted by IUPAC and endorsed by the ACS Committee on Nomenclature. The new names differ in only two cases from the names supported by the ACS Committee on Nomenclature and adopted by the ACS publications in 1995. From September 1997, dubnium replaced hahnium for element 105 and bohrium replaced nielsbohrium for element 107.

Table A.3. Names of transfermium elements 101–111

Element	New name	Symbol	Previous proposed name(s)	CAS RN
101	Mendelevium	Md	Mendelevium	7440-11-1
102	Nobelium	No	Nobelium	10028-14-5
103	Lawrencium	Lr	Lawrencium	22537-19-5
104	Rutherfordium	Rf	Kurchatovium	53850-36-5
105	Dubnium	Db	Hahnium, Joliotium	53850-35-4
106	Seaborgium	Sg	Seaborgium	54038-81-2
107	Bohrium	Bh	Nielsbohrium	54037-14-8
108	Hassium	Hs	Hahnium	54037-57-9
109	Meitnerium	Mt	Meitnerium	54038-01-6
110	Darmstadtium	Ds	Ununnilium	54083-77-1
111	Roentgenium	Rg	Unununium	n.a.

A.5 Selected Physical Properties of the Elements

See Table A.5, page 1186–1193.

A.6 Geochemical Classification of the Elements

Table A.4. Geochemical classification of the elements (after Goldschmidt[2])

Classes	Description	Examples
Lithophilic	Affinity to silicate materials	O, Si, Al, Mg, Ca, Na, K, Ti, Zr, Hf, Nb, Ta, W, Sn, U
Siderophilic	Affinity to iron	Fe, Co, Ni, PGMs
Chalcophilic	Affinity for sulfur forming sulfides, sulfosalts, and chalcogenides	Cu, Fe, Co, Ni, Hg, Cd, Os, Ir, Pt, Ru, Rh, Pd, Zn, Re, As, Sb, Se, Te
Hydrophilic	Affinity to water, and aqueous solutions (i.e., brines, geothermal fluids)	H, O, Na, K, Li, Cl, F, Mg
Atmophilic	Gaseous elements	H, O, N, He, Ar, rare gases
Biophilic	Animals and plants	C, H, O, N, P

[2] Goldschmidt, B. *J. Chem. Soc.* (1937) 55.

Table A.5. Properties of the elements

Element name (IUPAC)	Chemical abstract registry number [CARN]	Symbol (IUPAC)	Atomic number (Z)	Atomic relative mass (^{12}C=12.000) (IUPAC 2001)	Electronic configuration (ground state)	Spectral term (ground state)	Electronegativity (Pauling)	Crystal space lattice	Space group (Herman-Mauguin)	Pearson symbol	Strukturbericht and structure type	Lattice parameters (/pm)	Transition temperatures (α to β) (/°C)	Density (ρ/kg.m^{-3}) (298.15K)	Young's or elastic modulus (E/GPa)
Actinium	[7440-34-8]	Ac	89	[227]	[Rn]6d^{1}7s^2	$^2D_{3/2}$	1.10	fcc	Fm3m	*cF4*	A1 (Cu)	a = 531.11	n.a.	10060	25.0
Aluminum (Aluminium)	[7429-90-5]	Al	13	26.981538(2)	[Ne]3s^{2}3p^1	$^2P_{1/2}$	1.61	fcc	Fm3m	*cF4*	A1 (Cu)	a = 404.96	20.5 GPa	2698.9	70.2
Americium	[7440-35-9]	Am	95	[243]	[Rn]5f^{7}6d^{0}7s^2	$^8S_{7/2}$	1.30	hcp	P6$_3$/mmc	*hP4*	A3' (Mg)	a = 346.80 c = 1124.00	1074	13670	n.a.
Antimony (Stibium)	[7440-36-0]	Sb	51	121.760(1)	[Kr]4d^{10}5s^{2}5p^3	$^4S_{3/2}$	2.05	rhombic	R-3m	*hR2*	A7 (a-As)	a = 336.90 b = 533.00	nil	6696	54.7
Argon (gas)	[7440-37-1]	Ar	18	39.948(1)	[Ne]3s^{2}3p^6	$^2S_{1/2}$	n.a.	fcc	Fm3m	*cF4*	A1 (Cu)	a = 531.09	−189.2	1.784	w/o
Arsenic (α-)	[7440-38-2]	As	33	74.92160(2)	[Ar]3d^{10}4s^{2}4p^3	$^4S_{3/2}$	2.18	rhombic	R-3m	*hR2*	A7 (a-As)	a = 413.18 a = 54°10'	nil	5778	22
Astatine (α-)	[7440-68-8]	At	85	[210]	[Xe]4f^{14}5d^{10}6s^{2}6p^5	$^3P_{3/2}$	2.20	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
Barium	[7440-39-3]	Ba	56	137.327(7)	[Xe]6s^2	$^1S_0$	0.89	bcc	Im3m	*cI2*	A2 (W)	a = 502.30	370	3594	12.8
Berkelium	[7440-40-6]	Bk	97	[247]	[Rn]5f^{9}6d^{0}7s^2	$^6H_{15/2}$	1.30	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	14790	n.a.
Beryllium (α-)	[7440-41-7]	Be	4	9.012182(3)	[He]2s^2	$^1S_0$	1.57	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	a = 228.59 c = 358.42	1254	1847.70	318
Bismuth	[7440-69-9]	Bi	83	208.98038(2)	[Xe]4f^{14}5d^{10}6s^{2}6p^3	$^4S_{3/2}$	2.02	rhombic	R-3m	*hR2*	A7 (a-As)	a = 474.60 a = 57.23°	nil	9747	34
Bohrium	[54037-14-8]	Bh	107	[262]	[Rn]5f^{14}6d^{5}7s^2	n.a.	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Boron (β-)	[7440-42-8]	B	5	10.811(7)	[He]2s^{2}2p^1	$^2P_{1/2}$	2.04	rhombic	R-3m	*hR105*	β-B	a = 1014.5 a = 65°12'	nil	2340	440
Bromine (liquid, Br$_2$)	[7726-95-6]	Br	35	79.904(1)	[Ar]3d^{10}4s^{2}4p^5	$^3P_{3/2}$	2.96	orthorhombic	Cmca	*oC8*	A14 (I$_2$)	a = 668.00 b = 449.00 c = 874.00	−153	3122.60	w/o
Cadmium	[7440-43-9]	Cd	48	112.411(8)	[Kr]4d^{10}5s^2	$^1S_0$	1.69	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	a = 297.94 b = 561.86	nil	8650	62.6
Calcium (α-)	[7440-70-2]	Ca	20	40.078(4)	[Ar]4s^2	$^1S_0$	1.00	fcc	Fm3m	*cF4*	A1 (Cu)	a = 558.84	464	1550	19.6
Californium	[7440-71-3]	Cf	98	[251]	[Rn]5f^{10}6d^{0}7s^2	$^5I_8$	1.30	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Carbon (diamond)	[7782-40-3]	C	6	12.0107(8)	[He]2s^{2}2p^2	$^3P_0$	2.55	cubic	F-3md	*cF8*	A4 (diam.)	a = 356.69	n.a.	3513	980
Carbon (graphite)	[7440-44-0]	C	6	12.0107(8)	[He]2s^{2}2p^2	$^3P_0$	2.55	hexagonal	P6$_3$/mmc	*hP4*	A9 (graph.)	a = 246.16 c = 670.90	n.a.	2260	n.a.
Cerium (β-)	[7440-45-1	Ce	58	140.116(1)	[Xe]5d^{1}6s^{2}4f^1	$^3H_4$	1.12	d.hcp	P6$_3$/mmc	*hP4*	A3' (a-La)	a = 368.10 c = 1185.7	61	8240	33.6
Cesium (Caesium)	[7440-46-2]	Cs	55	132.90545(2)	[Xe]6s^1	$^2S_{1/2}$	0.79	bcc	Im3m	*cI2*	A2 (W)	a = 614.10	nil	1873	1.69
Chlorine (gas, Cl$_2$)	[7782-50-5]	Cl	17	35.4527(9)	[Ne]3s^{2}3p^5	$^3P_{3/2}$	3.16	orthorhombic	Cmca	*oC8*	A14 (I$_2$)	a = 624.00 b = 448.00 c = 826.00	−100.97	3214	w/o
Chromium	[7440-47-3]	Cr	24	51.9961(6)	[Ar]3d^{5}4s^1	$^7S_3$	1.66	bcc	Im3m	*cI2*	A2 (W)	a = 288.46	38.35	7190	279
Cobalt (ε-)	[7440-48-4]	Co	27	58.933200(9)	[Ar]3d^{7}4s^2	$^4F_{9/2}$	1.88	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	a = 250.71 c = 406.94	440.1120	8900	211
Copper (Cuprum)	[7440-50-8]	Cu	29	63.546(3)	[Ar]3d^{10}4s^1	$^2S_{1/2}$	1.90	fcc	Fm3m	*cF4*	A1 (Cu)	a = 361.51	nil	8960	129.8
Curium	[7440-51-9]	Cm	96	[247]	[Rn]5f^{7}6d^{1}7s^2	$^9D_2$	1.30	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	13300	n.a.
Darmstadtium	[54083-77-1]	Ds	110	[269]	[Rn]5f^{14}6d^{8}7s^2	n.a.	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Dubnium	[53850-35-4]	Db	105	[262]	[Rn]5f^{14}6d^{3}7s^2	$^3F_{3/2}$	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Dysprosium (α-)	[7429-91-6]	Dy	66	162.500(1)	[Xe]5d^{0}6s^{2}4f^{10}	$^5I_8$	1.22	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	a = 359.15 c = 565.01	1381	8551	61.4
Einsteinium	[7429-92-7]	Es	99	[252]	[Rn]5f^{11}6d^{0}7s^2	$^5I_{15/2}$	1.30	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Erbium	[7440-52-0]	Er	68	167.259(3)	[Xe]5d^{0}6s^{2}4f^{12}	$^3H_6$	1.24	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	a = 355.92 c = 558.50	nil	9066	69.9
Europium	[7440-53-1]	Eu	63	151.964(1)	[Xe]5d^{0}6s^{2}4f^7	$^8S_{7/2}$	n.a.	bcc	Im3m	*cI2*	A2 (W)	a = 458.27	nil	5243	18.2
Fermium	[7440-72-4]	Fm	100	[257]	[Rn]5f1^{2}6d^{0}7s^2	$^3H_6$	1.30	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.

Coulomb's or shear modulus (G/GPa)	Bulk or compression modulus (K/GPa)	Poisson's ratio (ν)	Melting point (m.p./°C)	Boiling point (b.p./°C)	Latent molar enthalpy of fusion (L_{fus}/kJ.mol^{-1})	Latent molar enthalpy of vaporization (L_{vap}/kJ.mol^{-1})	Thermal conductivity (k/W.m^{-1}.K^{-1}) (300K)	Specific heat capacity (c_p/J.kg^{-1}.K^{-1}) (300K)	Coefficient linear thermal expansion (α/10^{-6}K^{-1}) (0–100°C)	Electrical resistivity (ρ/μΩ.cm) (293.15K)	Temperature coefficient electrical resistivity (TCR/10^{-3}K^{-1})	Mass magnetic susceptibility ($4\pi\chi_m$/10^{-9}kg^{-1}m^3)	Absolute magnetic susceptibility (χ_m/10^{-6})	Thermal neutron capture cross section (σ_{th}/10^{-28}m^2)	Thermal neutron mass absorption coefficient ((μ/ρ)/cm^2.g^{-1})	Relative abundance Earth's crust (mg/kg)
n.a.	n.a.	n.a.	1046.9	3196.9	n.a.	n.a.	12	n.a.	14.9	n.a.	n.a	n.a.	n.a.	810	0.79000	5.5×10^{-10}
27.8	75.18	0.345	660.323	2466.9	10.711	294	237	903	23.03	2.6548	4.50	7.80	1.6752	0.233	0.00300	82300
n.a.	n.a.	n.a.	993.9	2606.9	14.4	238.5	est. 10	n.a.	n.a.	68	n.a	51.50	56.0229	74	n.a.	w/o
20.7	n.a.	0.250	630.7	1634.9	19.89	193.43	24.3	205	8.5	39	5.10	−10.90	−5.8081	5.4	0.01600	0.2
w/o	w/o	w/o	−189.20	−185.9	1.185	15.580	0.0177	524	–	w/o	w/o	−6.00	−0.0009	0.65	0.00600	3.5
n.a.	n.a.	n.a.	816.9	615.9	24.44	118.1	50	329	4.7	26	n.a	−3.90	−1.7932	4.3	0.02000	1.8
w/o	w/o	w/o	n.a.	n.a.	n.a.	n.a.	1.7	n.a.	n.a.	w/o	w/o	n.a.	n.a.	n.a.	n.a.	w/o
4.86	10.3	0.280	728.9	1636.9	7.66	140.3	18.4	205	18.1	50	6.49	11.30	3.2318	1.3	0.00270	425
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	est. 10	n.a.	n.a.	n.a.	n.a	n.a.	n.a.	710	n.a.	w/o
156	110	0.075	1282.9	2969.9	12.22	308.8	194–210	1.825	11.6	4.266	9.00	−12.60	−1.8526	0.0092	0.00030	2.8
12.8	34.965	0.330	271.4	1559.9	10.89	151	7.87	123	13.4	106.8	4.60	−1.70	−1.3186	0.034	0.00060	0.0085
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
n.a.	185.53	n.a.	2299.9	3657.9	50.20	480	27.6	1.107	5.0	6.500	n.a	−8.70	−1.6200	755	24.00000	10
w/o	w/o	w/o	−7.3	58.8	10.55	29.96	0.122	947	–	w/o	w/o	−4.90	−1.2176	6.8	0.02000	2.4
24	51	0.300	321.0	764.9	6.41	99.9	96.8	231	29.8	6.83	4.30	−2.30	−1.5832	2450	14.00000	0.15
7.85	17.45	0.310	838.9	1495.0	8.5395	154.7	200	647	22.3	3.43	4.17	13.80	1.7022	0.43	0.00370	41500
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a	n.a.	n.a.	2900	n.a.	w/o
n.a.	444	n.a.	3.820	5.100	117	n.a.	990–2320	509	1.2	1011	n.a	−6.20	−1.7332	0.0035	0.00015	200
n.a.	n.a.	n.a.	n.a.	n.a.	117	n.a.	5.70 (T) 1960 (//)	709	n.a.	1.375	n.a	−6.20	−1.1150	0.0035	0.00015	200
13.5	21.5	0.248	798.9	3425.9	5.23	398.00	11.4	192	8.5	82.8	8.70	220.00	144.2580	0.6	0.00210	66.5
0.67	2.693	0.295	28.4	674.82	2.087	63.9	35.9	236	97.0	18.8	6.00	2.80	0.4173	29	0.07700	3
w/o	w/o	w/o	−101.0	−33.97	6.406	20.410	0.0089	479	–	w/o	w/o	−7.20	−0.00184	35.5	0.33000	145
115.3	160.2	0.210	1856.9	2671.9	20.90	348.78	93.7	459.8	6.2	12.7	2.14	+44.5	25.4612	3.1	0.02100	102
82	181.5	0.320	1454.9	2731.2	15.50	382.4	99.2	421	13.4	6.24	6.60	ferromagnetic	w/o	37.2	0.21000	25
48.3	142.45	0.343	1084.62	2566.9	13.263	300.7	401	384.7	16.5	1.7241	4.38	−1.08	−0.7708	3.78	0.02100	60
n.a.	n.a.	n.a.	n.a.	n.a	14.64	395.70	est. 10	n.a.	n.a	n.a.	n.a	n.a.	n.a.	60	n.a.	w/o
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
n.a.	n.a.	n.a.	n.a.	n.a	n.a	n.a.	n.a.	n.a.		n.a.	n.a	n.a.	n.a.	n.a.	n.a.	w/o
24.7	40.5	0.237	1411.9	2561.9	11.06	280	10.7	170.5	9.9	92.6	n.a.	5450.00	3708.5449	920–1100	2.00000	5.2
n.a.	n.a.	n.a.	n.a	n.a	9.40	n.a.	n.a.	n.a.	n.a.	n.a.	n.a	n.a.	n.a.	160	n.a.	w/o
28.3	44.4	0.237	1528.9	2862.9	19.90	280	14.5	168	12.2	87	2.01	3770.00	2719.8641	160–170	0.36000	3.5
7.9	8.3	0.152	821.9	1596.9	9.21	176	13.9	182.3	35.0	90	n.a.	276.00	115.1540	4.300–4.600	6.00000	2
n.a.	n.a.	n.a.	n.a.	n.a.	1.02	3.3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	5800	n.a.	w/o

Table A.5. *(continued)*

Element name (IUPAC)	Chemical abstract registry number [CARN]	Symbol (IUPAC)	Atomic number (Z)	Atomic relative mass (^{12}C=12.000) (IUPAC 2001)	Electronic configuration (ground state)	Spectral term (ground state)	Electronegativity (Pauling)	Crystal space lattice	Space group (Herman-Mauguin)	Pearson symbol	Strukturbericht and structure type	Lattice parameters (/pm)	Transition temperatures (α to β) (/°C)	Density (ρ/kg.m^{-3}) (298.15K)	Young's or elastic modulus (E/GPa)
Fluorine (gas, F_2)	[7782-41-4]	F	9	18.9984032(3)	[He]$2s^22p^5$	$^2P_{3/2}$	3.98	monocl.	C2/c	*mC8*	a-F	*a* = 550.00	–227.60	1696	w/o
Francium	[7440-73-5]	Fr	87	[223]	[Rn]$7s^1$	$^2S_{1/2}$	0.70	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Gadolinium (α-)	[7440-54-2]	Gd	64	157.25(3)	[Xe]$5d^16s^24f^7$	$^9D_2$	1.20	hcp	$P6_3$/mmc	*hP2*	A3 (Mg)	a = 363.36 c = 578.10	1235	7901	54.8
Gallium	[7440-55-3]	Ga	31	69.723(1)	[Ar]$3d^{10}4s^24p^1$	$^2P_{1/2}$	1.81	orthorhombic	Cmca	*oC8*	A11 (a-Ga)	a = 451.86 b = 765.70 c = 452.58	nil	5907	9.81
Germanium	[7440-56-4]	Ge	32	72.64(1)	[Ar]$3d^{10}4s^24p^2$	$^3P_0$	2.01	cubic	Fd3m	*cF8*	A4 (Diamond)	a = 565.74	nil	5323	79.9
Gold (Aurum)	[7440-57-5]	Au	79	196.96655(2)	[Xe]$5d^{10}6s^14f^{14}$	$^2S_{1/2}$	2.54	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 407.82	nil	19320	78.5
Hafnium	[7440-58-6]	Hf	72	178.49(2)	[Xe]$5d^26s^24f^{14}$	$^3F_2$	1.30	hcp	$P6_3$/mmc	*hP2*	A3 (Mg)	*a* = 319.46 *c* = 505.11	1760	13310	141
Hassium	[54037-57-9]	Hs	108	[265]	[Rn]$5f^{14}6d^67s^2$	n.a.	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Helium (gas)	[7440-59-7]	He	2	4.002602(2)	$1s^2$	$^1S_0$	nil	hcp	$P6_3$/mmc	*hP2*	A3 (Mg)	a = 347.00	–269.20	0.1785	w/o
Holmium	[7440-60-0]	Ho	67	164.93032(2)	[Xe]$5d^06s^24f^{11}$	$^4I_{15/2}$	1.23	hcp	$P6_3$/mmc	*hP2*	A3 (Mg)	a = 357.78 c = 561.78	nil	8795	64.8
Hydrogen (gas, H_2)	[1333-74-0]	H	1	1.00794(7)	$1s^1$	$^2S_{1/2}$	2.20	fcc	Fm3m	*cF4*	A1 (Cu)	a = 533.80	–271.90	0.08988	w/o
Indium	[7440-74-6]	In	49	114.818(3)	[Kr]$4d^{10}5s^25p^1$	$^2P_{1/2}$	1.78	tetragonal	I4/mmm	*tI2*	A6 (In)	a = 325.30 c = 494.70	nil	7310	10.6
Iodine (solid, I_2)	[7553-56-2]	I	53	126.90447(3)	[Kr]$4d^{10}5s^25p^5$	$^3P_{3/2}$	2.66	orthorhombic	Cmca	*oC8*	A14 (I_2)	a = 726.97 b = 479.03 c = 979.42	nil	4930	n.a.
Iridium	[7439-88-5]	Ir	77	192.217(3)	[Xe]$5d^76s^24f^{14}$	$^4F_{9/2}$	2.20	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 383.91	nil	22650	528
Iron (Ferrum)	[7439-89-6]	Fe	26	55.845(2)	[Ar]$3d^64s^2$	$^5D_4$	1.83	bcc	Im3m	*cI2*	A2 (W)	*a* = 286.65	914.1391	7874	208.2
Krypton (gas)	[7439-90-9]	Kr	36	83.798(2)	[Ar]$3d^{10}4s^24p^6$	$^1S_0$	n.a.	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 581.00	–193	37493	w/o
Lanthanum (α-)	[7439-91-0]	La	57	138.9055(2)	[Xe]$5d^16s^24f^0$	$^2D_{3/2}$	1.10	d.h.c.p.	$P6_3$/mmc	*hP4*	A3' (a-La)	a = 377.40 c = 1217.10	868	6145	36.6
Lawrencium	[22537-19-5]	Lr	103	[262]	[Rn]$5f^{14}6d^17s^2$	$^2D_{5/2}$	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Lead (Plumbum)	[7439-92-1]	Pb	82	207.2(1)	[Xe]$4f^{14}5d^{10}6s^26p^2$	$^3P_0$	2.33	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 495.02	nil	11350	16.1
Lithium (β-)	[7439-93-2]	Li	3	6.941(2)	[He]$2s^1$	$^2S_{1/2}$	0.98	bcc	Im3m	*cI2*	A2 (W)	*a* = 350.93	–201.15	534	4.91
Lutetium	[7439-94-3]	Lu	71	174.967(1)	[Xe]$5d^16s^24f^{14}$	$^2D_{3/2}$	1.27	hcp	$P6_3$/mmc	*hP2*	A3 (Mg)	a = 350.52 c = 554.94	nil	9840	68.6
Magnesium	[7439-95-4]	Mg	12	24.3050(6)	[Ne]$3s^23p^0$	$^1S_0$	1.31	hcp	$P6_3$/mmc	*hP2*	A3 (Mg)	*a* = 320.94 *c* = 521.07	nil	1738	44.7
Manganese	[7439-96-5]	Mn	25	54.938049(9)	[Ar]$3d^54s^2$	$^6S_{5/2}$	1.55	*cubic*	I-43m	*cI58*	A12 (α-Mn)	*a* = 891.39	710, 1090, 1136	7440	191
Meitnerium	[54038-01-6]	Mt	109	[266]	[Rn]$5f^{14}6d^77s^2$	n.a.	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Mendelevium	[7440-11-1]	Md	101	[258]	[Rn]$5f^{13}6d^07s^2$	$^2F_{7/2}$	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Mercury (Hydrargyrum)	[7439-97-6]	Hg	80	200.59(2)	[Xe]$4f^{14}5d^{10}6s^26p^0$	$^1S_0$	2.00	rhombic	R-3m	*hR1*	A10 (α-Hg)	a = 300.50 α = 70.53°	–38.836	13546	w/o
Molybdenum	[7439-98-7]	Mo	42	95.94(1)	[Kr]$4d^55s^1$	$^7S_3$	2.16	bcc	Im3m	*cI2*	A2 (W)	a = 314.68	nil	10220	324.8
Neodymium (α-)	[7440-00-8]	Nd	60	144.24(3)	[Xe]$5d^06s^24f^4$	$^5I_4$	1.14	d.h.c.p.	$P6_3$/mmc	*hP4*	A3' (a-La)	a = 365.82 c = 1179.66	863	7007	41.4
Neon (gas)	[7440-01-9]	Ne	10	20.1797(6)	[He]$2s^22p^6$	$^1S_0$	1.14	cubic	Fm3m	*cF4*	A1 (Cu)	*a* = 446.20	–248.59	0.89994	w/o
Neptunium	[7439-99-8]	Np	93	237.0482	[Rn]$5f^46d^17s^2$	$^6L_{11/2}$	1.36	orthorhombic	Pnma	*oP8*	(a-Np)	a 472.30 b = 488.70 c= 666.30	280	20250	68.0
Nickel	[7440-02-0]	Ni	28	58.6934(2)	[Ar]$3d^84s^2$	$^3F_4$	1.91	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 352.38	358	8902	199.5
Niobium	[7440-03-1]	Nb	41	92.90638(2)	[Kr]$4d^45s^1$	$^6D_{1/2}$	1.60	bcc	Im3m	*cI2*	A2 (W)	*a* = 330.07	nil	8570	104.9
Nitrogen (gas, N_2)	[7727-37-9]	N	7	14.00674(7)	[He]$2s^22p^3$	$^4S_{3/2}$	3.04	cubic	Pa3	*cP8*	α-N	a = 566.1	–237.54	1.2506	w/o

Coulomb's or shear modulus (G/GPa)	Bulk or compression modulus (K/GPa)	Poisson's ratio (ν)	Melting point (m.p./°C)	Boiling point (b.p./°C)	Latent molar enthalpy of fusion (L_{fus}/kJ.mol^{-1})	Latent molar enthalpy of vaporization (L_{vap}/kJ.mol^{-1})	Thermal conductivity (k/W.m^{-1}.K^{-1}) (300K)	Specific heat capacity (c_p/J.kg^{-1}.K^{-1}) (300K)	Coefficient linear thermal expansion (α/10^{-6}K^{-1}) (0–100°C)	Electrical resistivity (ρ/μΩ.cm) (293.15K)	Temperature coefficient electrical resistivity (TCR/10^{-3}K^{-1})	Mass magnetic susceptibility ($4\pi\chi_m$/10^{-9}kg^{-1}m^3)	Absolute magnetic susceptibility (χ_m/10^{-6})	Thermal neutron capture cross section (σ_{th}/10^{-28}m^2)	Thermal neutron mass absorption coefficient ((μ/ρ)/cm^2.g^{-1})	Relative abundance Earth's crust (mg/kg)
w/o	w/o	w/o	−219.66	−188.12	0.510	6.620	0.0279	1.648	n.a.	w/o	w/o	n.a.	n.a.	0.0096	0.00020	585
n.a.	n.a.	n.a.	26.9	676.9	n.a.	n.a.	est. 15	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
21.8	37.9	0.259	1312.9	3265.9	10.50	301.5	10.6	235.9	9.4	134	1.76	ferromagnetic	w/o	49000	73.00000	6.2
6.67	51.02	0.470	29.7646	2402.9	5.594	254	40.6	371	18.3	27	n.a.	−3.00	−1.4102	2.9	0.01500	19
29.6	74.9	0.320	937.5	2829.9	36.9447	334	58.6	322	5.75	450000	n.a.	−1.50	−0.6354	2.2	0.01100	1.5
26	177.6	0.420	1064.18	2856.9	12.78	334	317	129	14.16	2.35	4.00	−1.78	−2.7366	98.7	0.17000	0.004
56	109	0.260	2229.9	4690.0	27.196	575.5	23	141.75	5.9	35.5	3.82	+5.3	5.6136	104	0.20000	3
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
w/o	w/o	w/o	−272.2	−269.2	0.0138	0.083	0.152	5.197	n.a.	w/o	w/o	−5.90	−0.00008	0.007	0.00010	0.008
26.3	40.2	0.231	1473.9	2694.9	16.80	71	16.2	164.9	11.2	81.4	1.71	5490.00	3842.3624	65	0.15000	1.3
w/o	w/o	w/o	−259.05	−252.85	0.117	0.904	0.1815	14.386	n.a.	w/o	w/o	−24.80	−0.0002	0.332	0.11000	1400
3.68	38.46	0.450	156.5985	2079.9	3.27	231.8	81.6	233	24.8	8.37	5.20	−1.40	−0.8144	194	0.60000	0.25
n.a.	0.0787	n.a.	113.6	184.4	15.78	41.6	0.449	429	n.a.	2E+15	n.a.	−4.50	−1.7654	6.2	0.01800	0.45
209	387.6	0.262	2409.9	4129.9	41.124	604.1	146.5	129.95	6.8	5.3	4.27	+1.67	3.0101	425	0.80000	0.001
81.6	169.8	0.291	1534.9	2749.9	15.20	340.4	80.2	447	11.8	9.71	6.51	ferromagnetic	w/o	2.56	0.01500	56300
w/o	w/o	w/o	−157.2	−153.4	1.370	9.080	0.0088	246.8	n.a.	w/o	w/o	−4.40	−0.0013	25	0.13000	0.0001
14.3	27.9	0.280	920.9	3456.9	8.37	402.1	13.5	195.1	4.9	57	2.18	11.00	5.3790	8.98	0.02300	39
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
5.59	45.8	0.440	327.46	1746.0	4.81	179.5	35.3	129	29.1	20.648	4.28	−1.50	−1.3548	0.171	0.00030	14
4.24	11.402	0.362	180.54	1346.97	2.93	147.109	84.7	3.547	56.0	8.55	4.35	+25.6	1.0879	0.045	n.a.	20
27.2	47.6	0.261	1662.9	3394.9	22.00	414	16.4	154	125.0	79	n.a.	1.20	0.9397	84	0.22000	0.8
17.3	35.6	0.291	648.9	1089.9	8.477	128.7	156	1.025	26.10	4.38	4.25	+6.8	0.9405	0.063	0.00100	23300
79.5	139.67	0.240	1243.9	2061.9	12.06	231.11	7.82	479	21.7	144	0.40	+121	71.6388	13.3	0.08300	950
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
w/o	w/o	w/o	−38.9	356.6	2.324	59.1	8.34	138	62.0	94.1	1.00	−2.10	−2.2637	374	0.63000	0.085
125.6	261.2	0.293	2621.85	4678.9	37.48	595	142	251	5.43	5.2	4.35	+11.7	9.5154	2.6	0.00900	1.2
16.3	31.8	0.281	1020.9	3067.9	7.14	289	16.5	190.3	6.7	64	1.64	480.00	267.6477	49	0.11000	41.5
w/o	w/o	w/o	−248.67	−246.1	0.335	1.710	0.0493	1.030	n.a.	w/o	w/o	−4.10	−0.0003	0.04	0.00600	0.005
n.a.	n.a.	n.a.	639.9	3901.9	3.20	336	6.3	n.a.	n.a.	122	n.a.	n.a.	n.a.	180	n.a.	w/o
76	177.3	0.312	1452.9	2731.9	17.16	377.5	90.7	471	13.3	6.844	6.92	ferromagnetic	w/o	37.2	0.02600	84
37.5	170.3	0.397	2467.9	4741.9	29.30	689.9	53.7	265.75	7.07	15.22	2.633	+27.6	18.8226	1.15	0.00400	20
w/o	w/o	w/o	−210.05	−195.85	0.720	5.577	0.02958	1.041	n.a.	w/o	w/o	−10.00	−0.0010	1.91	0.04800	19

Appendix A

Table A.5. *(continued)*

Element name (IUPAC)	Chemical abstract registry number [CARN]	Symbol (IUPAC)	Atomic number (Z)	Atomic relative mass (^{12}C=12.000) (IUPAC 2001)	Electronic configuration (ground state)	Spectral term (ground state)	Electronegativity (Pauling)	Crystal space lattice	Space group (Herman-Mauguin)	Pearson symbol	Strukturbericht and structure type	Lattice parameters (/pm)	Transition temperatures (α to β) (/°C)	Density (ρ/kg.m^{-3}) (298.15K)	Young's or elastic modulus (*E*/GPa)
Nobelium	[10028-14-5]	No	102	[259]	[Rn]5f^{14}6d^{0}7s^{2}	$^{1}S_{0}$	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Osmium	[7440-04-2]	Os	76	190.23(3)	[Xe]5d^{6}6s^{2}4f^{14}	$^{5}D_{4}$	2.20	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	*a* = 269.87 *c* = 431.97	nil	22590	558.6
Oxygen (gas, O_2)	[7782-44-7]	O	8	15.9994(3)	[He]2s^{2}2p^{4}	$^{3}P_{2}$	3.44	monocl.	C2m	*mC4*	α-O	*a* = 540.3 *b* = 342.9 *c* = 508.6 β = 132.53°	−249.38	1429	w/o
Palladium	[7440-05-3]	Pd	46	106.42(1)	[Kr]4d^{10}5s^{0}	$^{1}S_{0}$	2.20	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 389.03	nil	12020	121
Phosphorus (P_4)	[7723-14-0]	P	15	30.973761(2)	[Ne]3s^{2}3p^{3}	$^{4}S_{3/2}$	2.19	orthorhombic	Cmca	*cP8*	P (white)	*a* = 331.36 *b* = 1047.8 *c* = 437.63	nil	1820	30.4
Platinum	[7440-06-4]	Pt	78	195.078(2)	[Xe]5d^{9}6s^{1}4f^{14}	$^{3}D_{3}$	2.28	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 392.36	nil	21450	172.4
Plutonium	[7440-07-5]	Pu	94	[244]	[Rn]5f^{5}6d^{0}7s^{2}	$^{7}F_{0}$	1.28	monoclinic	P2$_1$/m	*mP16*	(α-Pu)	*a* = 618.30 *b* = 482.20 *c* = 1096.30 β = 101.79°	122	19840	87.5
Polonium	[7440-08-6]	Po	84	[209]	[Xe]4f^{14}5d^{10}6s^{2}6p^{4}	$^{3}P_{2}$	2.00	cubic	Pm3m	*cP1*	A$_h$ (a-Po)	a = 336.60	54	9320	26
Potassium (Kalium)	[7440-09-7]	K	19	39.0983(1)	[Ar]4s^{1}	$^{2}S_{1/2}$	0.82	bcc	Im3m	*cI2*	A2 (W)	*a* = 533.10	nil	862	3.175
Praseodymium (α-)	[7440-10-0]	Pr	59	140.90765(2)	[Xe]5d^{0}6s^{2}4f^{3}	$^{4}I_{9/2}$	1.13	d.h.c.p.	P6$_3$/mmc	*hP4*	A3' (a-La)	a = 367.21 c = 1183.26	795	6773	37.3
Promethium (α-)	[7440-12-2]	Pm	61	[145]	[Xe]5d^{0}6s^{2}4f^{5}	$^{6}H_{5/2}$	n.a.	d.h.c.p.	P6$_3$/mmc	*hP4*	A3' (a-La)	a = 365.00 c = 1165.00	890	7220	46.0
Protoactinium	[7440-13-3]	Pa	91	231.03588(2)	[Rn]5f^{2}6d^{1}7s^{2}	$^{4}K_{11/2}$	1.50	tetragonal	I4/mmm	*tI2*	A$_a$ (a-Pa)	a = 392.21	1170	15370	76.0
Radium	[7440-14-4]	Ra	88	[226]	[Rn]7s^{2}	$^{1}S_{0}$	0.89	bcc	Im3m	*cI2*	A2 (W)	a = 514.80	n.a.	c. 5000	13.2
Radon (gas)	[10043-92-2]	Rn	86	[222]	[Xe]4f^{14}5d^{10}6s^{2}6p^{6}	$^{1}S_{0}$	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	9073	w/o
Rhenium	[7440-15-5]	Re	75	186.207(1)	[Xe]5d^{5}6s^{2}4f^{14}	$^{6}S_{5/2}$	1.90	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	*a* = 276.08 *c* = 445.80	nil	21020	520
Rhodium	[7440-16-6]	Rh	45	102.90550(2)	[Kr]4d^{8}5s^{1}	$^{4}F_{9/2}$	2.28	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 380.32	nil	12410	379
Roentgenium	n.a.	Rg	111	[272]	[Rn]5f^{14}6d^{10}7s^{1}	n.a.	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Rubidium	[7440-17-7]	Rb	37	85.4678(3)	[Kr]5s^{1}	$^{2}S_{1/2}$	0.82	bcc	Im3m	*cI2*	A2 (W)	*a* = 570.50	nil	1532	2.35
Ruthenium	[7440-18-8]	Ru	44	101.07(2)	[Kr]4d^{7}5s^{2}	$^{5}F_{5}$	2.20	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	*a* = 270.58 *c* = 428.16	nil	12370	432
Rutherfordium	[53850-36-5]	Rf	104	[261]	[Rn]5f^{14}6d^{2}7s^{2}	$^{3}F_{2}$	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Samarium (α-)	[7440-19-9]	Sm	62	150.36(3)	[Xe]5d^{0}6s^{2}4f^{6}	$^{7}F_{0}$	1.17	rhombic	R-3m	*hR3*	C19 (a-Sm)	a = 362.86 c = 2620.70	922	7520	49.7
Scandium (α-)	[7440-20-2]	Sc	21	44.955910(8)	[Ar]4s^{2}4p^{1}	$^{2}D_{3/2}$	1.36	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	*a* = 330.88 *c* = 526.80	950	2989	74.4
Seaborgium	[54038-81-2]	Sg	106	[263]	[Rn]5f^{14}6d^{4}7s^{2}	n.a.	n.a.	n.a.	n.a.	*n.a.*	n.a.	n.a.	n.a.	n.a.	n.a.
Selenium (γ-)	[7782-49-2]	Se	34	78.96(3)	[Ar]3d^{10}4s^{2}4p^{4}	$^{3}P_{2}$	2.55	hexagonal	P3$_1$21	*hP3*	A8 (g-Se)	a = 436.59 c = 495.37	nil	4790	58
Silicon	[7440-21-3]	Si	14	28.0855(3)	[Ne]3s^{2}3p^{2}	$^{3}P_{0}$	1.90	cubic	F-3md	*cF8*	A4 (Diamond)	*a* = 543.102	nil	2329	113
Silver (Argentum)	[7440-22-4]	Ag	47	107.8682(2)	[Kr]4d^{10}5s^{1}	$^{2}S_{1/2}$	1.93	fcc	Fm3m	*cF4*	A1 (Cu)	a = 408.57	nil	10500	82.7
Sodium (Natrium)	[7440-23-5]	Na	11	22.989770(2)	[Ne]3s^{1}3p^{0}	$^{2}S_{1/2}$	0.93	bcc	Im3m	*cI2*	A2 (W)	*a* = 429.06	−268	971.2	6.8
Strontium	[7440-24-6]	Sr	38	87.62(1)	[Kr]5s^{2}	$^{1}S_{0}$	0.95	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 608.49	235, 540	2540	15.7
Sulfur (α-) (Sulphur)	[7704-34-9]	S	16	32.065(5)	[Ne]3s^{2}3p^{4}	$^{3}P_{2}$	2.58	orthorhombic	Fddd	*oF128*	A16 (a-S)	*a* = 104.64 *b* = 1286.60 *c* = 2448.60	93.55	2070	17.80
Tantalum	[7440-25-7]	Ta	73	180.9479(1)	[Xe]5d^{3}6s^{2}4f^{14}	$^{4}F_{3/2}$	1.50	bcc	Im3m	*cI2*	A2 (W)	*a* = 330.31	nil	16654	185.7
Technetium	[7440-26-8]	Tc	43	98.9062	[Kr]4d^{5}5s^{2}	$^{6}S_{5/2}$	1.90	hcp	P6$_3$/mmc	*hP2*	A3 (Mg)	a = 273.80 c = 439.30	n.a.	11500	407.00

Coulomb's or shear modulus (G/GPa)	Bulk or compression modulus (K/GPa)	Poisson's ratio (ν)	Melting point (*m.p.*/°C)	Boiling point (*b.p.*/°C)	Latent molar enthalpy of fusion (L_{fus}/kJ.mol^{-1})	Latent molar enthalpy of vaporization (L_{vap}/kJ.mol^{-1})	Thermal conductivity (k/W.m^{-1}.K^{-1}) (300K)	Specific heat capacity (c_p/J.kg^{-1}.K^{-1}) (300K)	Coefficient linear thermal expansion (α/10^{-6}K^{-1}) (0–100°C)	Electrical resistivity (ρ/μΩ.cm) (293.15K)	Temperature coefficient electrical resistivity (TCR/10^{-3}K^{-1})	Mass magnetic susceptibility ($4\pi\chi_m/10^{-9}$kg^{-1}m^3)	Absolute magnetic susceptibility ($\chi_m/10^{-6}$)	Thermal neutron capture cross section ($\sigma_{th}/10^{-28}$m^2)	Thermal neutron mass absorption coefficient ((μ/ρ)/cm^2.g^{-1})	Relative abundance Earth's crust (mg/kg)
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
223	383	0.250	3126.85	5026.9	57.855	746	87.6	129.84	4.57	8.12	4.10	+0.6	1.0786	15	0.02300	0.0015
w/o	w/o	w/o	−219.05	−183.05	0.445	6.820	0.02674	920	n.a.	w/o	w/o	+1335	0.1518	0.00028	0.00001	461000
43.6	187	0.394	1554.9	2963.9	16.736	362	71.8	244	11.76	10.8	3.77	+65.74	62.8817	6.9	0.02300	0.015
n.a.	n.a.	n.a.	44.15	279.9	2.64	56.5	0.235	744.5	n.a.	1E+17	nil	−11.30	−1.6366	0.18	0.00200	1050
60.9	284.9	0.397	1771.9	3826.9	22.175	510.5	71.6	131.47	9.1	9.81	3.92	+12.2	20.8246	10	0.02000	0.005
34.5	42.4	0.180	640.9	3231.9	2.90	333.5	6.74	133	55.0	146	+18.405	+31.70	50.0485	1.7	n.a.	w/o
n.a.	n.a.	n.a.	253.9	961.9	10.00	102.91	20	n.a.	n.a.	140	n.a.	n.a.	n.a.	0.5	n.a.	2×10^{-10}
1.28	4.201	0.350	63.65	766.39	2.334	76.735	102.4	754	83.0	6.15	5.70	6.70	0.4596	2.1	0.01800	20900
14.8	28.8	0.281	930.9	3511.9	6.89	331	12.5	193	6.8	68	1.71	423.00	227.9878	11.4	0.02900	9.2
18	33	0.280	1167.9	2726.9	7.13	289	est. 17.9	est. 185	n.a.	est. 50	n.a.	n.a.	n.a.	8000	n.a.	w/o
n.a.	n.a.	n.a.	1839.9	4000.0	12.34	481	est. 47	n.a.	n.a.	17.7	n.a.	32.50	39.7509	500	n.a.	1.4×10^{-6}
nil	nil	nil	699.9	1139.9	8.50	113	est. 18.6	n.a.	n.a.	100	n.a.	n.a.	n.a.	20	n.a.	9×10^{-7}
w/o	w/o	w/o	−71.2	−61.75	3.247	18.100	est. 0.00364	n.a.	n.a.	w/o	w/o	n.a.	n.a.	0.7	n.a.	4×10^{-13}
181	379	0.260	3184.85	5596.9	34.08	714.8	71.2	136	6.63	17.3	4.50	+4.56	7.6276	90	0.16000	0.0007
147	276	0.260	1963.9	3696.9	26.5935	494	150	243	8.5	4.51	4.30	+13.60	13.4308	145	0.63000	0.001
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
0.91	2.935	0.300	39.5	697.24	2.198	75.77	58.2	363.435	90.0	12.5	4.80	2.60	0.3170	0.38	0.00300	90
173	286	0.250	2336.9	4150.0	38.59	595.6	117	238	9.6	7.6	4.10	+5.42	5.3353	2.6	0.00900	0.001
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
19.5	37.8	0.274	1076.9	1790.9	8.92	165	13.3	181	n.a.	88	1.48	111.00	66.4249	5900	47.00000	7.05
29.7	56.6	0.279	1540.9	2830.9	14.10	332.7	15.8	567.7	10.2	61	2.80	+88	20.9314	27.2	0.25000	22
n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.		n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	w/o
6.46	8.621	0.450	216.9	685.0	6.28	95.48	2.04	321	37.0	106	n.a.	−4.00	−1.5247	11.7	0.05600	0.05
80.5	98	0.420	1409.9	3281.9	50.66	359	83.7	712	2.56	100000	n.a.	−1.60	−0.2965	171	0.00200	282000
30.3	105.3	0.367	961.78	2162.9	11.95	258	429	235	19.1	1.59	4.10	−2.27	−1.8967	63.6	0.20000	0.075
2.53	7.407	0.340	97.83	897.38	2.602	97.424	141	1.225	70.6	4.2	5.50	+8.8	0.6801	0.53	0.00700	23600
6.03	12.54	0.280	768.9	1383.9	8.40	136.9	35.3	301	23.0	23	3.82	+1.32	0.2668	1.2	0.00500	370
n.a.	7.692	n.a.	112.9	444.7	1.235	45	0.269	706	74.33	2E+15	nil	−6.20	−1.0213	0.52	0.00550	350
69.2	196.3	0.342	2995.9	5424.9	36.57	732.8	57.5	140	6.6	12.45	3.50	+10.7	14.1805	20.5	0.04100	2
162.00	31.06	0.260	2171.9	4876.9	33.29	585.2	0.206	708	n.a.	22.6	n.a.	34.20	31.2978	22	n.a.	w/o

Table A.5. *(continued)*

Element name (IUPAC)	Chemical abstract registry number [CARN]	Symbol (IUPAC)	Atomic number (Z)	Atomic relative mass (^{12}C=12.000) (IUPAC 2001)	Electronic configuration (ground state)	Spectral term (ground state)	Electronegativity (Pauling)	Crystal space lattice	Space group (Herman-Mauguin)	Pearson symbol	Strukturbericht and structure type	Lattice parameters (/pm)	Transition temperatures (α to β) (/°C)	Density (ρ/kg.m^{-3}) (298.15K)	Young's or elastic modulus (E/GPa)
Tellurium	[13494-80-9]	Te	52	127.60(3)	[Kr]$4d^{10}5s^25p^4$	$^3P_2$	2.10	hexagonal	$P3_121$	*hP3*	A8 (g-Se)	a = 445.66 c = 592.64	nil	6240	47.1
Terbium (α-)	[7440-27-9]	Tb	65	158.92534(2)	[Xe]$5d^06s^24f^9$	$^6H_{15/2}$	1.20	hcp	$P6_3/mmc$	*hP2*	A3 (Mg)	a = 360.55 c = 569.66	1289	8229	55.7
Thallium	[7440-28-0]	Tl	81	204.3833(2)	[Xe]$4f^{14}5d^{10}6s^26p^1$	$^2P_{1/2}$	1.62	hcp	$P6_3/mmc$	*hP2*	A3 (Mg)	a = 345.66 c = 552.48	230	11850	7.9
Thorium	[7440-29-1]	Th	90	232.0381(1)	[Rn]$6d^27s^2$	$^3F_2$	1.30	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 508.51	1360	11720	78.3
Thulium	[7440-30-4]	Tm	69	168.93421(2)	[Xe]$5d^06s^24f^{13}$	$^2F_{7/2}$	1.25	hcp	$P6_3/mmc$	*hP2*	A3 (Mg)	a = 353.75 c = 555.40	nil	9321	74
Tin (β-) (Stannum)	[7440-31-5]	Sn	50	118.710(7)	[Kr]$4d^{10}5s^25p^2$	$^3P_0$	1.96	*tetragonal*	$I4_1/amd$	*tI4*	A5 (β-Sn)	*a* = 581.97 *c* = 317.49	13	7298	49.9
Titanium (α-)	[7440-32-6]	Ti	22	47.867(1)	[Ar]$3d^24s^2$	$^3F_2$	1.54	hcp	$P6_3/mmc$	*hP2*	A3 (Mg)	*a* = 295.030 *c* = 468.312	882	4540	120.2
Tungsten (Wolfram)	[7440-33-7]	W	74	183.84(1)	[Xe]$5d^46s^24f^{14}$	$^5D_0$	2.36	bcc	Im3m	*cI2*	A2 (W)	*a* = 316.522	nil	19300	411
Uranium	[7440-61-1]	U	92	238.02891(3)	[Rn]$5f^36d^17s^2$	$^5L_6$	1.38	orthorhombic	Cmcm	*oC4*	A20 (a-U)	*a* = 285.38 *b* = 586.80 *c* = 495.57	662, 770	18950	177
Vanadium	[7040-62-2]	V	23	50.9415(1)	[Ar]$3d^34s^2$	$^4F_{3/2}$	1.63	bcc	Im3m	*cI2*	A2 (W)	a = 302.28	nil	6160	127.6
Xenon (gas)	[7040-63-3]	Xe	54	131.293(6)	[Kr]$4d^{10}5s^25p^6$	$^1S_0$	n.a.	fcc	Fm3m	*cF4*	A1 (Cu)	*a* = 635.00	−185	3540	w/o
Ytterbium	[7040-64-4]	Yb	70	173.04(3)	[Xe]$5d^06s^24f^{14}$	$^1S_0$	1.11	hcp	$P6_3/mmc$	*hP2*	A3 (Mg)	a = 364.82 c = 573.18	−3	6965	23.9
Yttrium	[7040-65-5]	Y	39	88.90585(2)	[Kr]$4d^15s^2$	$^2D_{3/2}$	1.22	hcp	$P6_3/mmc$	*hP2*	A3 (Mg)	a = 364.82 c = 573.18	1485	4469	63.5
Zinc	[7040-66-6]	Zn	30	65.409(4)	[Ar]$3d^{10}4s^2$	$^1S_0$	1.65	hcp	$P6_3/mmc$	*hP2*	A3 (Mg)	*a* = 266.48 *c* = 494.69	nil	7133	104.5
Zirconium	[7040-67-7]	Zr	40	91.224(2)	[Kr]$4d^25s^2$	$^3F_2$	1.33	hcp	$P6_3/mmc$	*hP2*	A3 (Mg)	*a* = 323.17 *c* = 574.76	862	6506	97.1

Coulomb's or shear modulus (G/GPa)	Bulk or compression modulus (K/GPa)	Poisson's ratio (ν)	Melting point (*m.p.*/°C)	Boiling point (*b.p.*/°C)	Latent molar enthalpy of fusion (L_{fus}/kJ.mol^{-1})	Latent molar enthalpy of vaporization (L_{vap}/kJ.mol^{-1})	Thermal conductivity (k/W.m^{-1}.K^{-1}) (300K)	Specific heat capacity (c_p/J.kg^{-1}.K^{-1}) (300K)	Coefficient linear thermal expansion (α/10^{-6}K^{-1}) (0–100°C)	Electrical resistivity (ρ/μΩ.cm) (293.15K)	Temperature coefficient electrical resistivity (TCR/10^{-3}K^{-1})	Mass magnetic susceptibility ($4\pi\chi_m$/10^{-9}kg^{-1}m^3)	Absolute magnetic susceptibility (χ_m/10^{-6})	Thermal neutron capture cross section (σ_{th}/10^{-28} m^2)	Thermal neutron mass absorption coefficient ((μ/ρ)/cm^2.g^{-1})	Relative abundance Earth's crust (mg/kg)
16.7	20.833	0.180	449.6	989.9	17.49	114.1	2.35	202	27.0	436000	n.a.	−3.90	−1.9366	5.4	0.01300	0.001
22.1	38.7	0.261	1355.9	3122.9	10.15	293	11.1	172	7.0	114	n.a.	13600.00	8905.8650	23	0.09000	1.2
2.7	28.5	0.450	303.5	1456.9	4.14	165	46.1	130	30.0	18	5.20	−3.00	−2.8290	3.4	0.00600	0.85
30.8	53.8	0.270	1749.984	4787.9	13.81	514.1	54	118	11.4–12.5	15.7	+3.567	+7.2	6.7151	7.4	0.01000	9.6
30.5	44.5	0.213	1544.9	1946.9	16.84	247	16.8	160	11.6	79	1.95	1990.00	1476.0658	105	0.25000	0.52
18.4	58.2	0.357	231.93	2269.9	7.08	296.10	66.6	229	21.1	11	4.65	−3.10	−1.8004	0.63	0.00200	2.3
45.6	108.4	0.361	1668.0	3286.9	19.41	428.9	21.9	537.8	8.35	42	3.80	+40.1	14.4874	6.1	0.04400	5650
160.6	311	0.280	3413.85	5656.9	52.31	806.8	174	132	4.59	5.65	4.80	+4.59	7.0495	18.4	0.03600	1.25
70.6	97.9	0.250	1132.4	3773.9	9.1420	417.1	27.6	116	12.6	30.8	+2.82	+21.6	32.5727	7.57	0.00500	2.7
46.7	158.73	0.365	1886.9	3376.9	21.50	451.8	30.7	489	8.3	24.8	3.90	+62.8	30.7844	5.06	0.03300	950
w/o	w/o	w/o	−111.76	−108.04	1.81	40.66	0.00569	158	n.a.	w/o	w/o	−4.30	−1.2113	25	0.08300	0.00001
9.9	30.5	0.207	823.9	1192.9	7.66	159	34.9	145	25.0	29	1.30	5.90	3.2701	35	0.07600	3.2
25.6	41.2	0.243	1521.9	3337.9	11.43	365	17.2	298	10.8	57	2.71	66.60	23.6851	1.28	0.00600	33
41.9	69.4	0.249	419.527	906.9	7.322	123.6	121	389	25.0	5.916	4.17	−2.21	−1.2539	1.1	0.00550	70
36.5	89.8	0.380	1854.7	4376.9	21.28	573	22.7	278	5.78	41	4.40	+16.8	8.6979	0.184	0.00660	165

Appendix A

B NIST Thermochemical Data for Pure Substances

Table B.1. NIST Molar Thermodynamic Properties of Pure Substances (298.15 K and 100 kPa)

Chemical compound	$\Delta_f H^0$	$\Delta_f G^0$	S^0	C_P^0
	/kJ.mol^{-1}		/J.K^{-1}.mol^{-1}	
Ag(s)	0.0	0.0	42.55	25.351
Ag(g)	284.55	245.65	172.997	20.786
Ag^+(g)	1021.73	–	–	–
Ag_2CO_3(s)	–505.8	–436.8	167.4	112.26
Ag_2O(s)	–31.05	–11.20	121.3	65.86
Ag_2S(s)(argentite)	–32.59	–40.67	144.01	76.53
AgCN(c)	146.0	156.9	107.19	66.73
AgCNS(s)	87.9	101.39	131.0	63.
AgCl(s)(cerargyrite)	–127.068	–109.789	96.2	50.79
AgBr(s)	–100.37	–96.90	107.1	52.38
AgI(s)	–61.83	–66.19	115.5	56.82
$AgNO_3$(s)	–124.39	–33.47	140.92	93.05
Ag_3PO_4(s)	–	–879.	–	–
Ag_2CrO_4(s)	–731.74	–641.76	217.6	142.26
Ag_2SO_4(s)	–715.88	–618.41	200.4	131.38
Al(s)	0.0	0.0	28.33	24.35
Al(g)	326.4	285.7	164.54	21.38
Al^{3+}(g)	5483.17	–	–	–
$Al(OH)_3$	–1276.	–	–	–
$AlCl_3$(s)	–704.2	–628.8	110.67	91.84
$AlCl_3$(g)	–583.2	–	–	–
Al_2O_3(s)(alumina)	–1675.7	–1582.3	50.92	79.04
B(s)	0.0	0.0	5.86	11.09

Table B.1. *(continued)*

Chemical compound	$\Delta_f H^0$	$\Delta_f G^0$	S^0	C_p^0
	/kJ.mol^{-1}		/J.K^{-1}.mol^{-1}	
BF_3(g)	−1137.00	−1120.35	254.01	50.46
$BaCO_3$(s)	−1216.3	−1137.6	112.1	85.35
BaC_2O_4(s)	−1368.6	–	–	–
$BaCrO_4$(s)	−1446.0	−1345.22	158.6	–
BaF_2(s)	−1207.1	−1156.8	96.36	71.21
$BaSO_4$(s)	−1473.2	−1362.2	132.2	101.75
Bi(s)	0.0	0.0	56.74	25.52
Bi_2S_3(s)	−143.1	−140.6	200.4	122.2
Br_2(l)	0.0	0.0	152.231	75.689
Br_2(g)	30.907	3.110	245.463	36.02
Br(g)	111.88	82.429	174.91	20.786
Br^-(g)	−219.07	–	–	–
C(s) (graphite)	0.0	0.0	5.740	8.527
C(s) (diamond)	1.895	2.900	2.377	6.113
C(g)	716.682	671.257	158.096	20.838
CO(g)	−110.525	−137.168	197.674	29.42
CO_2(g)	−393.509	−394.359	213.74	37.11
$COCl_2$(g)	−218.8	−204.6	283.53	57.66
CH_4(g)	−74.81	−50.72	186.264	35.309
C_2H_2(g)	226.73	209.20	200.94	43.93
C_2H_4(g)	52.25	68.12	219.45	43.56
C_2H_6(g)	−84.68	−32.82	229.60	52.63
C_3H_6(g)	20.2	62.72	266.9	64.
C_3H_8(g)	−104.5	−23.4	269.9	7.
C_4H_{10}(g)	−126.5	−17.15	310.1	97.4
C_5H_{12}(g)	−146.5	−8.37	348.9	120.2
C_8H_{18}(g)	−208.5	16.40	466.7	189.
CH_3OCH_3(g)	−184.05	−112.59	266.38	64.39
CH_3OH(g)	−200.66	−162.00	239.70	43.89
CH_3OH(l)	−238.66	−166.36	126.8	81.6
C_2H_5OH(g)	−235.10	−168.49	282.70	65.44
C_2H_5OH(l)	−277.69	−174.78	160.7	111.46
CH_3COOH(l)	−484.51	−389.9	159.8	124.3
$(CH_3)_2O$(g)	−184.05	−112.59	266.38	64.39
CH_3CHO(l)	−192.30	−128.20	160.2	–
CH_3Cl(g)	−80.83	−57.37	234.58	40.75
$CHCl_3$(g)	−103.14	−70.34	295.71	65.69
CCl_4(l)	−135.44	−65.27	216.40	131.75
C_6H_6(g)	82.9	129.7	269.2	81.6
C_6H_6(l)	49.0	124.7	172.	132.
C_6H_{12}(l)	−156.3	26.7	204.4	157.7

Table B.1. *(continued)*

Chemical compound	$\Delta_f H^0$	$\Delta_f G^0$	S^0	C_p^0
	/kJ.mol^{-1}		/J.K^{-1}.mol^{-1}	
CaO(s)	–635.09	–604.03	39.75	42.80
$Ca(OH)_2$(s)	–986.09	–898.49	83.39	87.49
$CaCO_3$(s)(calcite)	–1206.92	–1128.79	92.9	81.88
$CaCO_3$(s)(aragonite)	–1207.13	–1127.75	88.7	81.25
CaC_2O_4(s)	–1360.6	–	–	–
CaF_2(s)	–1219.6	–1167.3	68.87	67.03
$Ca_3(PO_4)_2$(s)	–4109.9	–3884.7	240.91	231.58
$CaSO_4$(s)	–1434.11	–1321.79	106.7	99.66
Cd(s)	0.0	0.0	51.76	25.98
Cd(g)	2623.54	–	–	–
Cd^{2+}(g)	112.01	77.41	167.746	20.786
$Cd(OH)_2$(s)	–560.7	–473.6	96.	–
CdS(s)	–161.9	–156.5	64.9	–
Cl2(g)	0.0	0.0	223.066	33.907
Cl(g)	121.679	105.680	165.198	21.840
Cl^-(g)	–233.13	–	–	–
ClO_2(g)	102.5	120.5	256.84	41.97
Cu(s)	0.0	0.0	33.150	24.35
Cu(g)	338.32	298.58	166.38	20.786
CuC_2O_4(s)	–	–661.8	–	–
$CuCO_3.Cu(OH)_2$(s)	–1051.4	–893.6	186.2	–
Cu_2O(s)	–168.6	–146.0	93.14	63.64
CuO(s)	–157.3	–129.7	42.63	42.30
$Cu(OH)_2$(s)	–449.8	–	–	–
Cu_2S(s)	–79.5	–86.2	120.9	76.32
CuS(s)	–53.1	–53.6	66.5	47.82
F_2(g)	0.0	0.0	202.78	31.30
F(g)	78.99	61.91	158.754	22.744
F^-(g)	–255.39	–	–	–
Fe(s)	0.0	0.0	27.28	25.10
Fe(g)	416.3	370.7	180.490	25.677
Fe^{2+}(g)	2749.93	–	–	–
Fe^{3+}(g)	5712.8	–	–	–
$Fe_{0.947}O$ (s)	–266.27	–245.12	57.49	48.12
Fe_2O_3(s)	–824.2	–742.2	87.40	103.85
Fe_3O_4(s)	–1118.4	–1015.4	146.4	143.43
$Fe(OH)_3$(s)	–823.0	–696.5	106.7	–
Fe_3C(s)	25.1	20.1	104.6	105.9
$FeCO_3$(c,siderite)	–740.57	–666.67	92.9	82.13
FeS(s)(pyrrhotite)	–100.0	–100.4	60.29	50.54
FeS_2(s)	–178.2	–166.9	52.93	62.17

Table B.1. *(continued)*

Chemical compound	$\Delta_f H^0$	$\Delta_f G^0$	S^0	C_p^0
	/kJ.mol^{-1}		/J.K^{-1}.mol^{-1}	
H_2(g)	0.0	0.0	130.684	28.824
H(g)	217.965	203.247	114.713	20.784
H^+(g)	1536.202	–	–	–
H_2O(g)	–241.818	–228.572	188.825	33.577
H_2O(l)	–285.830	–237.129	69.91	75.291
H_2O_2(g)	–136.31	–105.57	232.7	43.1
H_2O_2(l)	–187.78	–120.35	109.6	89.1
H_2S(g)	–20.63	–33.56	205.79	34.23
H_2SO_4(l)	–813.989	–690.003	156.904	138.91
HF(g)	–271.1	–273.2	173.779	29.133
HCl(g)	–92.307	–95.299	186.908	29.12
HBr(g)	–36.40	–53.45	198.695	29.142
HI(g)	26.48	1.70	206.594	29.158
HCN(g)	135.1	124.7	201.78	35.86
Hg(l)	0.0	0.0	76.02	27.983
$HgCl_2$(s)	–224.3	–178.6	146.0	–
Hg_2Br_2(s)	–206.90	–181.075	218.	–
Hg_2Cl_2(s)	–265.22	–210.745	192.5	–
HgS(s)(red)	–58.2	–50.6	82.4	48.41
HgS(s)(black)	–53.6	–47.7	88.3	–
Hg_2SO_4(s)	–743.12	–625.815	200.66	131.96
I_2(s)	0.0	0.0	116.135	54.438
I_2(g)	62.438	19.327	260.69	36.90
I(g)	106.838	70.250	180.791	20.786
I^-(g)	–197.	–	–	–
ICl(g)	17.78	–5.46	247.551	35.56
K(s)	0.0	0.0	64.18	29.58
K(g)	89.24	60.59	160.336	20.786
K^+(g)	514.26	–	–	–
KF(s)	–567.27	–537.75	66.57	49.04
KCl(s)	–436.747	–409.14	82.59	51.30
KBr(s)	–393.798	–380.66	95.90	52.30
KI(s)	–327.900	–324.892	106.32	52.93
$KClO_4$(s)	–432.75	–303.09	151.0	112.38
KNO_3(s)	–494.63	–394.86	133.05	96.40
Mg(s)	0.0	0.0	32.68	24.89
Mg^{2+}(g)	2348.504	–	–	–
MgF_2(s)	–1123.4	–1070.2	57.24	61.59
$MgCO_3$(s)	–1095.8	–1012.1	65.7	75.52
$Mg(OH)_2$(s)	–924.54	–833.51	63.18	77.03
Mn(s)	0.0	0.0	32.01	26.32

Table B.1. *(continued)*

Chemical compound	$\Delta_f H^0$	$\Delta_f G^0$	S^0	C_p^0
	/kJ.mol^{-1}		/J.K^{-1}.mol^{-1}	
MnO_2(s)	−520.03	−465.14	53.05	54.14
MnS(s)(green)	−214.2	−218.4	78.2	49.96
N_2(g)	0.0	0.0	191.61	29.125
N(g)	472.704	455.563	153.298	20.786
NH_3(g)	−46.11	−16.45	192.45	35.06
NH_4Cl(s)	−314.43	−202.87	94.6	84.1
NO(g)	90.25	86.55	210.761	29.844
NO_2(g)	33.18	51.31	240.06	37.20
N_2O(g)	82.05	104.20	219.85	38.45
N_2O_4(g)	9.16	97.89	304.29	77.28
N_2O_4(l)	−19.50	97.54	209.2	142.7
N_2O_5(g)	11.3	115.1	355.7	84.5
N_2O_5(s)	−43.1	113.9	178.2	143.1
NOCl(g)	51.71	66.08	261.69	44.69
NOBr(g)	82.17	82.42	273.66	45.48
Na(s)	0.0	0.0	51.21	28.24
Na(g)	107.32	76.761	153.712	20.786
Na^+(g)	609.358	–	–	–
NaF(s)	−573.647	−543.494	51.46	46.86
NaCl(s)	−411.153	−384.138	72.13	50.50
NaBr(s)	−361.062	−348.983	86.82	51.38
NaI(s)	−287.78	−286.06	98.53	52.09
Na_2CO_3(s)	−1130.68	−1044.44	134.98	112.30
$NaNO_2$(s)	−358.65	−284.55	103.8	–
$NaNO_3$(s)	−467.85	−367.00	116.52	92.88
Na_2O(s)	−414.22	−375.46	75.06	69.12
NiS(s)	−82.0	−79.5	52.97	47.11
O_2(g)	0.0	0.0	205.138	29.355
O_3(ozone)	142.7	163.2	238.93	39.20
O^-(g)	249.170	231.731	161.055	21.912
P(s)(white)	0.0	0.0	41.09	23.840
P(g)	314.64	278.25	163.193	20.786
PH_3(g)	5.4	13.4	210.23	37.11
PCl_3(g)	−287.0	−267.8	311.78	71.84
PCl_5(g)	−374.9	−305.0	364.58	112.80
Pb(s)	0.0	0.0	64.81	26.44
Pb(g)	195.0	161.9	175.373	20.786
$PbBr_2$(s)	−278.9	−261.92	161.5	80.12
$PbCl_2$(s)	−359.41	−314.10	−136.0	–
PbO(s)(minium)	−218.99	−189.93	66.5	45.81
PbO(s)(litharge)	−217.32	−187.89	68.70	45.77

Table B.1. *(continued)*

Chemical compound	$\Delta_f H^0$	$\Delta_f G^0$	S^0	C_p^0
	/kJ.mol^{-1}		/J.K^{-1}.mol^{-1}	
PbO_2(s)	−277.4	−217.33	68.6	64.64
Pb_3O_4(s)	−718.4	−601.2	211.3	146.9
$Pb(OH)_2$(s)	–	−452.2	–	–
PbS(s)(galena)	−100.4	−98.7	91.2	49.50
$PbSO_4$(s)	−919.94	−813.14	148.57	103.207
S(s)(rhombic)	0.0	0.0	31.80	22.64
S(s)(monoclinic)	0.33	–	–	–
S(g)	278.805	238.250	167.821	23.673
SF_6(g)	−1209.	−1105.3	291.82	97.28
SO_2(g)	−296.830	−300.194	248.22	39.87
SO_3(g)	−395.72	−371.06	256.76	50.67
SO3(l)	−441.04	−373.75	113.8	–
SO_2Cl_2(g)	−364.0	−320.0	311.94	77.0
Sn(s)(white)	0.0	0.0	51.55	26.99
Sn(s)(grey)	−2.09	0.13	44.14	25.77
SnO(s)	−285.8	−256.9	56.5	44.31
SnO_2(s)	−580.7	−519.6	52.3	52.59
SnS(s)	−100.	−98.3	77.0	49.25
Tl(s)	0.0	0.0	64.18	26.32
Tl^+(g)	777.764	–	–	–
Tl^{3+}(g)	5639.2	–	–	–
Zn(s)	0.0	0.0	41.63	25.40
Zn^{2+}(g)	2782.78	–	–	–
ZnO(s)	−348.28	−318.30	43.64	40.25
ZnS(s)(wurtzite)	−192.63	–	–	–
ZnS(s)(sphalerite)	−205.98	−201.29	57.7	46.0

Notes: (s) crystalline solid, (l) liquid, and (g) gas. After Wagman, D.D., et al. The NBS Tables of Chemical Thermodynamic Properties *J. Phys. Chem. Ref. Data*, 11, Suppl. 2 (1982)

C Natural Radioactivity and Radionuclides

C.1 Introduction

During the formation of the Earth, 4.65 billion years ago, along with the stable nuclides, several radionuclides were formed. Those that were radioactive with a half-life too short with respect to the formation of the Earth obviously disappeared. On the other hand, those with half-lives of the same order of magnitude or greater than that of the formation of Earth are mainly responsible for the natural radioactivity of the Earth's crust materials (i.e., ice, river, sea and ocean waters, minerals, ores, rocks, and soils). Today, over 60 radionuclides occur in the environment, and they can be grouped into three main categories:

(i) ***Primordial radionuclides*** are radionuclides present since the formation of the Earth. Primordial radionuclides are usually subdivided into two groups:

   (1) radionuclides that occur individually (i.e., non-series) and decay directly to a stable end nuclide such as: ^{50}V, ^{87}Rb, ^{113}Cd, ^{115}In, ^{123}Te, ^{138}La, ^{142}Ce, ^{144}Nd, ^{147}Sm, ^{152}Gd, ^{174}Hf, ^{176}Lu, ^{187}Re, ^{190}Pt, ^{192}Pt, ^{209}Bi;

   (2) those that occur in radioactive decay chains and end in a stable isotope of lead through a sequence of decaying daughter species with a wide-range of half-lives headed by the parent radionuclides: ^{238}U, ^{235}U, and ^{232}Th.

(ii) ***Cosmogenic radionuclides*** or ***cosmonuclides*** are radionuclides formed by nuclear interaction between primary and secondary cosmic radiations (i.e., cosmic rays) and the nuclides present in the upper atmosphere; a typical example is carbon-14.

(iii) ***Artificial radionuclides*** are radionuclides enhanced or produced by human activities (e.g., atmospheric nuclear weapons experiments, wastes from nuclear power reactors, and industries involved in the nuclear fuel cycle); a typical example is tritium.

C.2 Mononuclidic Elements

Mononuclidic elements are chemical elements that occur in nature and consist of only one nuclide isotope; they are sometimes also called ***monoisotopic***. They are listed in Table C.1.

Table C.1. Mononuclidic elements (isotopes)

Isotopes
^{4}He, ^{9}Be, ^{19}F, ^{23}Na, ^{27}Al, ^{31}P, ^{45}Sc, ^{55}Mn, ^{59}Co, ^{75}As, ^{89}Y, ^{93}Nb, ^{103}Rh, ^{127}I, ^{133}Cs, ^{141}Pr, ^{159}Tb, ^{165}Ho, ^{169}Tm, ^{197}Au, ^{209}Bi, ^{231}Pa

C.3 Nuclear Decay Series

Primordial radionuclides that yield a long sequence of decaying radionuclides with a wide-range of half-lives and end up as a stable isotope of lead are called natural radioactive ***decay chains*** or ***nuclear series***. They are typically long-lived radionuclides, often with half-lives of the order of hundreds of millions of years. In nature, there exist only three such decay series, headed by the parent radionuclides uranium-238 or ^{238}U (4n + 2), uranium-235 or ^{235}U (4n + 3), and thorium-232 or ^{232}Th (4n), and one artificial series headed by neptunium-237 or ^{237}Np (4n + 1). These series are commonly called the ***uranium series***, the ***actinium series***, the ***thorium series***, and the ***neptunium series***, respectively. The number in parentheses represents the parity of the mass number (A) of all the decaying radionuclides inside the series. The detailed list of radionuclides in each series is presented with former names and symbols, atomic masses, half-lives, decay type and radiation energies in the tables below. Close examination of these tables shows that each decay series ends with a stable lead isotope, ^{208}Pb, ^{207}Pb and ^{206}Pb, respectively, called radiogenic lead isotopes by contrast with the naturally occurring nonradiogenic lead isotope ^{204}Pb. Usually, unless there are exceptional geologic conditions (i.e., intense weathering and lixiviation, cation exchange with surrounding water or seawater, geochemical migration processes in ore deposits), in nature both uranium and thorium isotopes are in secular equilibrium with their decaying daughters. That is, all decaying daughters in the same series exhibit an activity equal to that of the parent radionuclide, and hence the activities of all radionuclides within each series are nearly equal.

Table C.2. General characteristics of the three natural and the artificial radioactive decay series

Mass number parity (A)	Decay series name	Header radionuclide ($T_{1/2}$ and $E\alpha$) Natural isotopic abundance	Specific activity of parent radionuclide (*)	End stable nuclide (*)	Gaseous radioelement (emanation, old symbol)
4n	Thorium-232	^{232}Th (14.10 Ga; 4.08 MeV) a_{232} = 100 at.%	4.046 MBq/kg of Th_{nat}	^{208}Pb	^{220}Rn, (Thoron, Tn)
4n+1	Neptunium-237 (artificial)	^{237}Np (2.14 Ma; 4.96 MeV) a_{237} = nil at.% (artificial)	26.098 GBq/kg	^{209}Bi	none
4n+2	Uranium-238 – Radium	^{238}U (4.468 Ga; 4.19 MeV) a_{238} = 99.2745 at.%	12.355 MBq/kg of U_{nat}	^{206}Pb	^{222}Rn (Radon, Rn)
4n+3	Uranium-235 – Actinium	^{235}U (703.8 Ma; 4.6793 MeV) a_{235} = 0.72000 at.%	0.569 MBq/kg of U_{nat}	^{207}Pb	^{223}Rn (Actinon, An)

Important note: (*) Specific activity of the parent radionuclide alone without considering the activity of each decaying radionuclides in secular equilibrium with it. (**) The three stable lead isotopes are the ultimate daughters of the three natural decay series, and hence are called *radiogenic* lead isotopes by contrast with the naturally occurring lead isotope ^{204}Pb.

Table C.3. Natural decay series of uranium-238 (4n + 2)

Radionuclide	Historical name (Symbol)	Atomic mass (M_A/u)	Half-life ($T_{1/2}$)	Radioactivity	
				Decay type	Maximum energy (E_{max}/MeV)
Uranium-238	Uranium I (UI)	238.05077	4.468×10^9 a	α (γ)	4.268
Thorium-234	UX_1	234.043583	24.1 d	β (γ)	0.060
Protoactinium-234m	UX_2	234.043298	1.17 min	β (γ)	0.868 (0.009)
Uranium-234	Uranium II (UII)	234.040904	244,500 a	α (γ)	4.856
Thorium-230	Ionium (Io)	230.033087	77,000 a	α (γ)	4.767
Radium-226	Radium (^{226}Ra)	226.02536	1602 a	α (γ)	4.869
Radon-222	Radon (^{222}Rn)	222.017531	3.8235 d	α (γ)	5.587
Polonium-218	Radium A (RaA)	218.00893	3.05 min	α (γ)	6.110
Lead-214	Radium B (RaB)	213.999766	26.8 min	β (γ)	0.60 (0.296)
Bismuth-214	Radium C (RaC)	213.998686	19.7 min	β (γ)	2.349 (1.570)
Polonium-214	Radium C' (RaC')	213.995201	163.7 µs	α (γ)	7.835
Lead-210	Radium D (RaD)	209.984187	22.26 a	β (γ)	0.047
Bismuth-210	Radium E (RaE)	209.984121	5.013 d	β (γ)	0.444
Polonium-210	Polonium (^{210}Po)	209.982876	138.378 d	α (γ)	5.408
Lead-206	Radium G (RaG)	205.974468	stable end nuclide		

Table C.4. Natural decay series of uranium-235 (4n + 3)

Radionuclide	Historical name (Symbol)	Atomic mass (M_A/u)	Half-life ($T_{1/2}$)	Radioactivity	
				Decay type	Maximum energy (E_{max}/MeV)
Uranium-235	Actinouranium (AcU)	235.043915	703.8×10^6 a	α (γ)	4.681 (0.067)
Thorium-231	Uranium Y (UY)	231.036291	25.52 h	β (γ)	0.210
Protoactinium-231	Protoactinium (^{231}Pa)	231.035877	32,760 a	α (γ)	5.148 (0.037)
Actinium-227	Actinium (^{227}Ac)	227.027753	21.773 a	β (γ)	0.085
Thorium-227	Radioactinium (RdAc)	227.027706	18.718 d	α (γ)	6.145 (0.130)
Francium-223	Actinium K (AcK)	223.019736	22 min	β (γ)	0.395 (0.004)
Radium-223	Actinium X (AcX)	223.018501	11.434 d	α (γ)	5.977 (0.011)
Radon-219	Actinon (An)	219.009481	3.96 s	α (γ)	6.944 (0.033)
Polonium-215	Actinium A (AcA)	214.999423	1.78 ms	α (γ)	7.524
Lead-211	Actinium B (AcB)	210.988742	36.1 min	β (γ)	0.564 (0.066)
Bismuth-211	Actinium C (AcC)	210.98730	2.13 min	α (γ)	6.730 (0.056)
Thallium-207	Actinium C" (AcC")	206.97745	4.77 min	β (γ)	0.510 (0.001)
Lead-207	Actinium D (AcD)	206.975903	stable end nuclide		

Table C.5. Natural decay series of thorium-232 (4n)

Radionuclide	Historical name (Symbol)	Atomic mass (M_A/u)	Half-life ($T_{1/2}$)	Radioactivity	
				Decay type	Maximum energy (E_{max}/MeV)
Thorium-232	Thorium (^{232}Th)	232.038124	14.10×10^9 a	α (γ)	4.080
Radium-228	Mesothorium 1 (MsTh1)	228.031139	6.7 a	β (γ)	0.013
Actinium-228	Mesothorium 2 (MsTh2)	228.03108	6.13 h	β (γ)	1.480 (1.020)
Thorium-228	Radiothorium (RdTh)	228.02875	1.910 a	α (γ)	5.521 (0.001)
Radium-224	Thorium X (ThX)	224.020218	3.64 d	α (γ)	5.787 (0.014)
Radon-220	Thoron (Tn)	220.011401	55 s	α (γ)	6.405
Polonium-216	Thorium A (ThA)	216.001922	0.15 s	α (γ)	6.670
Lead-212	Thorium B (ThB)	211.991905	10.64 h	β (γ)	0.440(0.210)
Bismuth-212	Thorium C (ThC)	211.991279	60.6 min	α β (γ)	2.929 (0.290)
Polonium-212	Thorium C' (ThC')	211.988866	304 ns	α (γ)	8.954
Thallium-208	Thorium C" (ThC")	207.982013	3.10 min	β (γ)	3.929 (3.414)
Lead-206	Thorium D (ThD)	205.974468	stable end nuclide		

C.4 Non-Series Primordial Radionuclides

Table C.6. Non-series primordial radionuclides

Chemical element	Relative atomic mass ($^{12}C = 12.000$)	Radionuclides (s)	Stable nuclides	Relative isotopic abundance (a/%at.)	Half-life ($T_{1/2}/y$)	Decay type, maximum energy	Specific radioactivity of the chemical element (A_m/kBq.kg^{-1})
Potassium	39.0983	^{40}K	^{40}Ca, ^{40}Ar	0.0117	1.277×10^{9}	β^-(1.32MeV) 89.28%, (EC, β^+) 10.72%	30.996
Cadmium	112.4110	^{113}Cd	^{131}In	12.2200	9.3×10^{15}	β^-(0.59)	0.00155
Vanadium	50.9415	^{50}V	^{50}Cr, ^{50}Ti	0.2500	1.40×10^{17}	β^-, EC	0.0000046
Rubidium	85.4678	^{87}Rb	^{87}Sr	27.8350	4.88×10^{10}	β^-(0.273)	882.743
Indium	114.8180	^{115}In	^{115}Sn	95.7100	4.4×10^{14}	β^-(0.496)	0.2505879
Tellurium	127.6000	^{123}Te	^{123}Sb	0.9080	1.3×10^{13}	EC (0.051)	0.0724031
		^{130}Te	^{130}Xe	33.7990	2.5×10^{21}	$2\beta^-$	0.000000014
Lanthanum	138.9055	^{138}La	^{138}Ce, ^{138}Ba	0.0902	1.06×10^{11}	β^-(1.04)34%, CE(1.75) 66%	0.8103017
Neodymium	144.2400	^{144}Nd	^{140}Ce	23.8000	2.29×10^{15}	α(1.83)	0.00953
Samarium	150.3600	^{147}Sm	^{143}Nd	15.0200	1.06×10^{11}	α(2.15)	124.651
		^{148}Sm	^{144}Nd	11.3000	7.00×10^{15}	α(1.96)	0.0014201
		^{149}Sm	^{145}Nd	13.8000	1.00×10^{16}	α	0.0012140
Gadolinium	157.250	^{152}Gd	^{148}Sm	0.2000	1.1×10^{14}	α(2.24)	0.00153
Lutetium	174.9670	^{176}Lu	^{176}Hf, ^{176}Yb	2.5900	3.80×10^{10}	β^-(1.02)97%, CE 3%, γ	51.526
Hafnium	178.4900	^{174}Hf	^{170}Yb	0.1620	2.00×10^{15}	α(2.55)	0.0000600
Rhenium	186.2070	^{187}Re	^{187}Os	62.9300	4.56×10^{10}	β^-(0.0025)	981
Osmium	190.2300	^{186}Os	^{182}W	1.5800	2.00×10^{15}	α (2.75)	0.0005493
Platinum	195.0780	^{190}Pt	^{186}Os	0.0100	6.5×10^{11}	α (3.18)	0.0104314

C.5 Cosmogenic Radionuclides

Table C.7. Major cosmogenic radionuclides

Cosmonuclide	Symbol	Half-life ($T_{1/2}$)	Decay type, maximum energy (E_m/MeV)
Tritium	^{3}T (^{3}H)	12.43 years	β^-(0.018)
Beryllium-7	^{7}Be	53.29 days	CE (0.477)
Beryllium-10	^{10}Be	1.5×10^6 years	β^- (0.555)
Carbon-14	^{14}C	5730 years	β^- (0.15648)
Sodium-22	^{22}Na	2.605 years	β^+ (2.842) 90%, EC 10%, γ
Aluminum-26	^{26}Al	7.4×10^5 years	β^+ (4.003) 82%, EC
Silicon-32	^{32}Si	172 years	β^-(0.227)
Phosphorus-32	^{32}P	14.262 days	β^-(1.710)
Phosphorus-33	^{33}P	25.56 days	β^-(0.249)
Sulfur-35	^{35}S	87.44 days	β^-(0.1674)
Chlorine-36	^{36}Cl	3.01×10^5 years	β^-(0.709)
Chlorine-39	^{39}Cl	55.6 min	β^-(1.50)
Argon-39	^{39}Ar	269 years	β^-(0.57)
Krypton-81	^{81}Kr	2.29×10^5 years	EC (0.287)

C.6 NORM and TENORM

About 68% of the total amount of radioactivity on Earth is of natural origin, i.e., both primordial and cosmogenic radionuclides, while the remaining 32% is due to human activities.

NORM is an internationally adopted acronym for **N**aturally **O**ccurring **R**adioactive **M**aterial while **TENORM** stands for **T**echnologically-**E**nhanced **N**aturally **O**ccurring **R**adioactive **M**aterial.

Historically, a material was arbitrarily defined as ***radioactive*** when it exhibited a specific activity greater than 74 $kBq.kg^{-1}$ (i.e., 2 $nCi.g^{-1}$); later this value was converted into 70 $kBq.kg^{-1}$.

Table C.8. International regulations regarding definition of radioactive materials

Organization	Specific activity (Bq/g)
IAEA	70 kBq/kg
IAEA	10 Bq/g for (^{238}U + ^{232}Th)
Japan	(U + 0.4 Th) < 50 ppm wt.
US DOT	(U + Th) < 500 ppm wt.

C.7 Activity Calculations

C.7.1 Activity of a Material Containing One Natural Radionuclide

The activity of a mass of material m containing a mass fraction w_X of a naturally occurring radionuclide ^{A}X of half-life $T_{1/2}$ and isotopic abundance a_X is given by the following equation:

$$A_X = \lambda_X \cdot N_X = (\ln 2/T_{1/2}) \cdot (N_A \cdot a_X \cdot w_X \cdot m/M_X)$$

with

A activity of radionuclide ^{A}X in Bq
λ_X radioactive decay constant of radionuclide ^{A}X in s^{-1}
$T_{1/2}$ half-life of the radionuclide X in s
N_A Avogadro's constant $6.02204532 \times 10^{23}$ mol^{-1}
a_X dimensionless atomic isotopic abundance
w_X dimensionless mass fraction of the radionuclide in the material
m mass of material in kg
M_X atomic molar mass of radionuclide in $kg.mol^{-1}$.

Therefore, the activity per unit mass of material, called the ***specific activity***, denoted a_m, and expressed in $Bq.kg^{-1}$, is given by the following equation:

$$a_m = A_X/m = (\ln 2/T_{1/2}) \cdot (N_A \cdot a_X \cdot w_X/M_X)$$

C.7.2 Activity of a Material Containing Natural U and Th

Natural uranium consists of the three radioactive isotopes (see Uranium): namely ^{238}U, ^{235}U, and to a lesser extent ^{234}U with both uranium-238 and uranium-235 being the parent radionuclides of the two independent radioactive decay series (4n + 3) and (4n + 2) respectively, while uranium-234 is a decay product of the uranium-238 series. Therefore, the specific activity of natural uranium (U_{nat}) corresponds to the activities of the three isotopes including all the individual activities of all their decaying radionuclides. Therefore for a naturally occurring radioactive material containing a mass fraction w_U of natural uranium, the specific activities of the two parent radionuclides are given by:

$$a_{235} = (\ln 2/T_{235}) \cdot (N_A \cdot a_{235} \cdot w_U/M_U)$$

$$a_{238} = (\ln 2/T_{238}) \cdot (N_A \cdot a_{238} \cdot w_U/M_U)$$

Assuming secular equilibrium for the two decay chains, the activity of ^{234}U is equal to that of its parent radionuclide, i.e., ^{238}U, and is simply given by:

$$a_{234} = a_{238}$$

Therefore, for natural uranium, the specific activities of the three isotopes are: ^{238}U contributes to 12.369 $MBq.kg^{-1}$, ^{234}U contributes to 12.369 $MBq.kg^{-1}$ while ^{235}U contributes only 568 $kBq.kg^{-1}$. However, because the two parent radionuclides are also in secular equilibrium with all their decaying daughters, the total specific activity of natural uranium in secular equilibrium is given by the previous specific activities multiplied by the number of decaying radionuclides in each decay chain as follows:

$$a_{Unat} = 14 \cdot a_{238} + 11 \cdot a_{235} = (N_A \cdot \ln 2 \cdot w_U/M_U) \cdot [(11 \cdot a_{235}/T_{235}) + (14 \cdot a_{238}/T_{238})]$$

Therefore, the total specific activity of natural uranium metal in secular equilibrium and considering all the activities of its daughter radionuclides is 179.414 $MBq.kg^{-1}$.

Similarly, natural thorium is a mononuclidic element, i.e., it has only one radioactive isotope thorium-232, parent radionuclide of the natural decay chain (4n), therefore, for a naturally occurring radioactive material containing a mass fraction w_{Th} of natural thorium, the specific activity of the parent radionuclide is given by:

$$a_{232} = (\ln 2/T_{232})\cdot(N_A\cdot w_{Th}/M_{Th})$$

Therefore, for natural thorium, the specific activity of the radionuclide ^{232}Th is 4.046 $MBq.kg^{-1}$. However, because the radionuclide is also in secular equilibrium with all its decaying daughters, the total specific activity of natural thorium in secular equilibrium is given by the previous specific activity times the number of decaying radionuclides in the 4n decay chain as follows:

$$a_{Th} = 11 \cdot a_{232} = 11 \cdot (\ln 2/T_{232})\cdot(N_A\cdot w_{Th}/M_{Th})$$

Then the total activity of the material is given by:

$$a_{Total} = a_{Unat} + a_{Th} = (N_A\cdot\ln 2)\cdot\{(w_U/M_U)\cdot[(11\cdot a_{235}/T_{235})+(14\cdot a_{238}/T_{238})]+(w_{Th}/M_{Th})\cdot(11/T_{232})\}$$

The alpha radiation of the eight alpha-emitting nuclides contained in the U-238 series and, to a lesser degree, of the seven alpha emitters in the U-235 series presents a radiation hazard on ingestion or inhalation of uranium ore (i.e., dust) and radon, while gamma radiation, mainly from Pb-214 and Bi-214, together with beta radiation of Th-234, Pa-234m, Pb-214, Bi-214, and Bi-210, presents an external radiation hazard.

D Crystallography and Crystallochemistry

D.1 Direct Space Lattice Parameters

A crystal is a periodic array of ordered entities (e.g., ions, atoms, molecules) in three dimensions. The repeating unit is imagined to be a unit cell whose volume and shape are designated by the three vectors representing the length and direction of the cell edges as three unit vectors of translation.

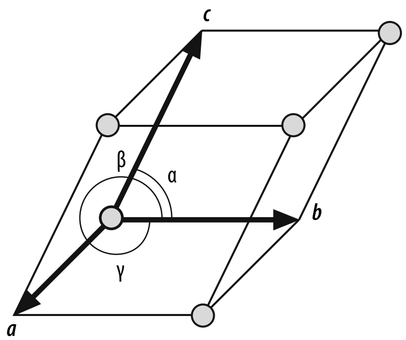

Figure D.1. IUCr standardized notation for space lattice parameters

A space lattice is defined by either the three unit lattice vectors $\boldsymbol{a}$, $\boldsymbol{b}$, and $\boldsymbol{c}$ or the set of the six lattice parameters: a, b, c, α, β, and γ, where the last three quantities represent the plane angles between the cell edges. The International Union of Crystallography (IUCr) has now standardized the notation and definition of space lattice parameters and this international standard nomenclature is listed below:

$\alpha \equiv \text{mes}\ (\boldsymbol{b}, \boldsymbol{c})$	and	plane $A \equiv (\boldsymbol{b}, \boldsymbol{c})$
$\beta \equiv \text{mes}\ (\boldsymbol{c}, \boldsymbol{a})$	and	plane $B \equiv (\boldsymbol{c}, \boldsymbol{a})$
$\gamma \equiv \text{mes}\ (\boldsymbol{a}, \boldsymbol{b})$	and	plane $C \equiv (\boldsymbol{a}, \boldsymbol{b})$

There are seven possible space lattices which entirely describe both inorganic and organic crystalline materials. These are called the seven crystal systems (i.e., cubic, tetragonal, hexagonal, trigonal, orthorhombic, monoclinic, and triclinic).

D.2 Symmetry Elements

Table D.1. Symmetry element notations

Symmetry element	Notation		Symmetry operation
	International Hermann–Mauguin	Old Schonflies–Fedorov	
Center	*1*	Ci	Center of inversion
Reflection plane (mirror)	*m*	C_s	Single reflection plane of symmetry
n-fold rotation axis	*n*	C_n	*n*-fold rotation axis with $n = 2, 3, 4$, and 6, the angle of rotation, *A*, expressed in radians is given by the following relation $A(\text{rad}) = 2\pi/n$.
Inversion axis	*n*	C_{ni}	Vertical *n*-fold rotation axis followed, by an inversion by a symmetry center lying on the axis. (2 = m, 3, 4 =, 6)
Glide plane	*a*, *b*, *c*, *n*, *d*	–	Reflection in a plane followed by a translation according to a vector parallel to the plane. Translation in the ***a*** direction: a, Translation in the ***b*** direction: b, Translation in the ***c*** direction: c, Translation in the $1/2(\boldsymbol{a} + \boldsymbol{b})$ or face diagonal direction: n, Translation in the $1/2(\boldsymbol{a} + \boldsymbol{b} + \boldsymbol{c})$ or volume diagonal direction: d.
Screw axis	n_m	–	Vertical *n*-fold axis, followed by a translation parallel to the axis
Rotary-reflection axis	$\sim n$	S_n	Point group with an *n*-fold axis of rotary reflection.

Table D.2. Five platonic regular polyhedrons

Regular polyhedron	Description	Volume	Surface area	No. of faces	No. of edges	No. of vertices
Tetrahedron	Equilateral triangles	$a^3\sqrt{2}/12$	$a^2\sqrt{3}$	4	6	4
Octahedron	Equilateral triangle	$a^3\sqrt{2}/3$	$2a^2\sqrt{3}$	8	12	6
Hexahedron (cube)	Square	a^3	$6a^2$	6	12	8
Pentagonal dodecahedron	Regular pentagon	$a^3(15+7\sqrt{5})/4$	$3a^2[5(5+2\sqrt{5})]^{1/2}$	12	30	20
Icosahedron	Equilateral triangle	$5a^3(3+\sqrt{5})/12$	$5a^2\sqrt{3}$	20	30	12

D.3 The Seven Crystal Systems

Table D.3. The seven crystal systems

Crystal system	Synonyms, old names	Symbol	Geometrical description	Symmetry Hermann–Mauguin (Schoenflies–Fedorov)	Lattice parameters (IUCr) (edges length, interaxial angles)
Cubic	isometric	**C** (c)	Cube	$m3m$ (O_h)	$a = b = c$ $\alpha = \beta = \gamma = \pi/2$ rad
Hexagonal		**H** (h)	Upright prism with a regular hexagonal basis	$6/mmm$ (D_{6h})	$a = b \neq c$ $\alpha = \beta = \pi/2$ rad and $\gamma = 2\pi/3$ rad
Tetragonal	quadratic	**T** (t)	Upright prism with a square basis	$4/mmm$ (D_{4h})	$a = b \neq c$ $\alpha = \beta = \gamma = \pi/2$ rad
Rhombohedral	trigonal	**R** (h)	Prism with each face equal to identical lozenges	$3m$ (D_{3d})	$a = b = c$ $\alpha = \beta = \gamma \neq \pi/2$ rad
Orthorhombic	orthogonal	**O** (o)	Upright prism with a rectangular basis	mmm (D_{2h})	$a \neq b \neq c$ $\alpha = \beta = \gamma = \pi/2$ rad
Monoclinic	clinorhombic	**M**(m)	Inclined prism with a rectangular basis	$2/m$ (C_{2h})	$a \neq b \neq c$ $\alpha = \gamma = \pi/2$ rad and $\beta > 2\pi/3$ rad
Triclinic	anorthic	**T** (a)	Uneven prism	1 (C)	$a \neq b \neq c$ $\alpha \neq \beta \neq \gamma \neq \pi/2$ rad

D.4 Conversion of a Rhombohedral to a Hexagonal Lattice

The rhombohedral unit cell is defined by three equal-length unit translations *a*, and the plane angle between them, α. The rhombohedral lattice parameters can be converted to hexagonal by using the following equations:

$$a_H = 2a_R \sin(\alpha/2)$$

$$c_H = 3\,[a_R^{\,2} - 2a_H^{\,2}/3]^{1/2}$$

D.5 The 14 Bravais Space Lattices

See Table D.4, page 1212.

D.6 Characteristics of Close-Packed Arrangements

See Table D.5, page 1212.

Table D.4. The 14 Bravais space lattices

Crystal System	Bravais space lattice	ASTM notation	Hermann–Mauguin symbol	Pearson notation
Cubic	Primitive cell	C	P	*cP1*
	Body-centered	B	I	*cI2*
	Face-centered	F	F	*cF4*
Hexagonal	Primitive cell	H	P	*hP2*
Tetragonal	Primitive cell	T	P	*tP1*
	Body-centered	U	I	*tI2*
Rhombohedral	Primitive cell	R	R	*hR1*
Orthorhombic	Primitive cell	O	P	*oP1*
	Base-centered	Q	A, B, C	*oA2*
	Body-centered	P	I	*oI2*
	Face-centered	S	F	*oF4*
Monoclinic	Primitive cell	M	P	*mP1*
	Base-centered	N	A, B, C	*mP2*
Triclinic	Primitive cell	A	P	*aP1*

Note: P primitive, **I** body-centered (from German, *Innercentrum*), **F** face-centered (From German, *Flaschencentriert*), **A**, **B**, **C** faces orthogonals to lattice vectors **a**, **b** and **c** respectively.

Table D.5. Characteristics of close-packed-arrangements

Parameters	Simple cubic	Body-centered cubic	Face-centered cubic	Hexagonal close-packed
Notation	c.s., *P*	bcc, *I*	fcc, *F*	hcp
Unit cell volume	a^3	a^3	a^3	$a^2c\sqrt{3}/2$
Number of entities per unit cell	1	2	4	2
Primitive cell volume	a^3	$a^3/2$	$a^3/4$	$a^2c\sqrt{3}/12$
Number of first neighboring entities (coordination number)	6	8	12	12
Number of second neighboring entities	12	6	6	12
Smallest distance between 1st neighbors	a	$a\sqrt{3}/2 \cong 0.866a$	$a/\sqrt{2} \cong 0.707a$	a
Smallest distance between 2nd neighbors	$a\sqrt{2} = 1.414a$	a	a	$a\sqrt{3}$
Packing fraction	$\pi/6 \cong 0.524$	$\pi\sqrt{3}/8 \cong 0.680$	$\pi\sqrt{2}/6 \cong 0.740$	$\pi\sqrt{2}/6 \cong 0.740$

D.7 The 32 Classes of Symmetry

They are 10 elements of symmetry in crystals. These 10 symmetry operators can be combined in 32 ways to produce the 32 point groups tabulated in Table D.7.

Table D.6. Schoenflies–Fedorov point group notation

Notation	Description
C_n	Point group with a single *n*-fold rotation axis
C_{nh}	Point group with a single vertical *n*-fold rotation axis, together with a horizontal mirror plane
C_{nv}	Point group with a single vertical *n*-fold rotation axis, together with n vertical mirror plane
D_n	Point group with a single vertical *n*-fold rotation axis, together with two-fold rotation axis perpendicular to it.
V	Alternative symbol to D_2
O	Holohedral cubic point group
T	Tetartohedral cubic point groups
S_n	Point group with an n-fold axis of rotary reflection
i	Center of inversion
s	Single plane of symmetry
d	Diagonal reflection plane, bisecting the angle between two horizontal axes

Table D.7. The 32 classes of symmetry

Crystal system	Hermann–Mauguin	Schoenflies–Fedorov	Crystal morphology [names of classes according to Von Groth]	Typical mineral	Class No.
Cubic	*m3m*	O_h	Cubic hexaoctahedral (= holohedral)	Galena, PbS	32
	$\bar{4}3m$	T_d	Cubic hexatetrahedral (= tetrahedral)	Sphalerite, ZnS	31
	m3	T_h	Cubic dyakis-dodecahedral (= diploidal, or pyritohedral)	Pyrite, FeS_2	30
	432	O	Cubic pentagonal icositetrahedral (= gyroidal, or plagiohedral)	Cuprite, Cu_2O	29
	23	T	Cubic tetrahedral-pentagonal dodecahedral (= tetartohedral)	Ullmannite, NiSSb	28
Hexagonal	*6/mmm*	D_{6h}	Dihexagonal-dipyramidal (= holohedral)	Beryl, $Be_3Al_2[Si_6O_{18}]$	27
	6mm	C_{6v}	Dihexagonal-pyramidal (= hemimorphic)	Greenockite, CdS	26
	6/m	C_{6h}	Hexagonal-dipyramidal (= pyramidal)	Apatite, $Ca_5(PO_4)_3(F,OH, Cl)$	25
	622	D_6	Hexagonal trapezohedral (= trapezohedral)	Kalsilite	24
	6	C_6	Hexagonal pyramidal (= tetartohedral)	Nepheline, $KNa_3Si_4Al_4O_{16}$	23
	$\bar{6}m2$	D_{3h}	Ditrigonal-dipyramidal (= trigonal holohedral)	Benitoite, $BaTiSi_3O_9$	22
	–6	C_{3n}	Trigonal-dipyramidal	Silver o-phosphate Ag_2HPO_4	19

Appendix D

Table D.7. *(continued)*

Crystal system	Hermann–Mauguin	Schoenflies–Fedorov	Crystal morphology [names of classes according to Von Groth]	Typical mineral	Class No.
Trigonal (= Rhombohedral)	$\bar{3}m$	C_{3d}	Hexagonal scalenoedral (= ditrigonal pyramidal, holohedral)	Calcite, $CaCO_3$	21
	3m	C_{3v}	Ditrigonal-pyramidal (=hemimorphic hemihedral)	Tourmaline	20
	32	D_3	Trigonal-trapezohedral	α-Quartz, SiO_2	18
	–3	$S_5 = C_{3i}$	Trigonal-rhomboedral	Dolomite, $CaMg(CO_3)_2$	17
	3	C_3	Trigonal-pyramidal (= tetartohedral)	Sodium periodate, $NaIO_4$	16
Tetragonal	*4/mmm*	D_{4h}	Ditetragonal-dipyramidal (= holohedral)	Zircon, $ZrSiO_4$	15
	4mm	C_{4v}	Ditetragonal-pyramidal (= hemimorphic hemihedral)	Diaboleite, $2Pb(OH)_2.CuCl_2.6H_2O$	14
	4/m	C_{4h}	Tetragonal-dipyramidal (= paramorphic hemihedral)	Scheelite, $CaWO_4$	13
	422	D_4	Tetragonal-trapezohedral (= enantiomorphic hemihedral)	Phosgenite, NiSO4	12
	$\bar{4}2m$	$V_4 = D_{2d}$	Tetragonal scalenohedral (= sphenoidal, hemihedral of 2nd sort)	Chalcopyrite, $CuFeS_2$	11
	4	C_4	Tetragonal-pyramidal (= tetartohedral)	Wulfenite, $PbMoO_4$	10
	$\bar{4}$	S_4	Tetragonal-disphenoidal (= ogdohedral)	Cahnite, $Ca_4B_2As_2O_{12}.4H_2O$	9
Orthorhombic	*mmm*	$V_h = D_{2h}$	Orthorhombic-dipyramidal (= holohedral)	Baryte, $BaSO_4$	8
	mm2	C_{2v}	Orthorhombic-pyramidal (=hemimorphic hemihedral)	Topaz,	7
	222	$V = D_2$	Orthorhombic-disphenoidal (= enantiomorphic hemihedral)	Sulfur, S_8	6
Monoclinic	*2/m*	C_{2h}	Rhomboidal prismatic (= holohedral)	Gypsum, $CaSO_4$	5
	m	$C_{h1} = C_S$	Monoclinic domatic (= clinohedral, hemihedral)	Clinohedrite, $CaZnHSiO_5$	4
	2	C_2	Monclinic sphenoidal (= hemimorphic hemihedral)	Tartaric acid	3
Triclinic	$\bar{1}$	Ci	Triclinic pinacoidal (= holohedral)	Axinite, $CuSO_4$	2
	1	C_1	Triclinic asymetric (= pedial, hemihedral)	Calcium thiosulfate, CaS_2O_3	1

D.8 Strukturbericht Structures

Table D.8. Strukturbericht designations for pure elements (i.e., A type)

Designation	Typical example (Mineral name)	Crystal system	Hermann–Mauguin	Pearson's
A_a	α-Protoactinium	Tetragonal	*I4/mmm*	*tI2*
A_b	β-Uranium	Tetragonal	*P4nm*	*tP30*
A_c	α-Neptunium	Orthorhombic	*Pmcn*	*oP8*
A_d	β-Neptunium	Tetragonal	$P42_1$	*tP4*
A_e	β-$TiCu_3$	Orthorhombic	*Cmcm*	*oC4*
A_f	$HgSn_{10}$	Hexagonal	*P6/mmm*	*hP1*
A_g	γ-Boron	Tetragonal	*P4n2*	*tP50*
A_h	α-Polonium	Cubic	*Pm3m*	*cP1*
A_i	β-Polonium	Rhombohedral	*R3m*	*tR1*
A_k	α-Selenium	Monoclinic	$P2_1/n$	*mP32*
A_l	β-Selenium	Monoclinic	$P2_1/a$	*mP32*
A1	Copper	Cubic fcc	*Fm3m*	*cF4*
A2	Tungsten	Cubic bcc	*Im3m*	*cI2*
A3	Magnesium	Hexagonal hcp	$P6_3/mmc$	*hP2*
A4	Diamond	Cubic	*Fd3m*	*cF8*
A5	β-Tin, white	Tetragonal	*I4/amd*	*tI4*
A6	Indium	Tetragonal	*F4/mmm*	*tF4*
A7	α-Arsenic	Rhombohedral	*R3m*	*hR2*
A8	γ-Selenium	Trigonal	$P3_221$	*hP3*
A9	Graphite	Hexagonal	$P6_3/mmc$	*hP4*
A10	α-Mercury	Rhombohedral	*R3m*	*hR1*
A11	α-Gallium	Orthorhombic	*Cmca*	*oC8*
A12	α-Manganese	Cubic	*I43m*	*cI58*
A13	β-Manganese	Cubic	$P4_13$	*cP20*
A14	Iodine (I_2)	Orthorhombic	*Pm3n*	*cP8*
A15	β-Tungsten (W_3O), or Cr_3Si	Cubic	*Pm3n*	*cP8*
A16	α-Sulfur (S_4)	Orthorhombic	*Fddd*	*oF128*
A17	Phosphorus (Black)	Orthorhombic	*Cmca*	*oC8*
A19	Polonium	Monoclinic	*n.a.*	*n.a.*
A20	α-Uranium	Orthorhombic	*Cmcm*	*oC4*

Table D.9. Strukturbericht designations for binary compounds (AX type)

Designation	Typical example (Mineral name)	Crystal system	Hermann–Mauguin	Pearson's
B_a	CoU	Cubic	*$I2_13$*	*cI16*
B_b	ζ-AgZn	Hexagonal	*P3*	*hP9*
B_c	CaSi	Orthorhombic	*Cmmc*	*oC8*
B_d	η-NiSi	Orthorhombic	*Pbnm*	*oP8*
B_e	CdSb	Orthorhombic	*Pbca*	*oP16*
B_f	CrB	Orthorhombic	*Cmcm*	*oC8*
B_g	MoB	Tetragonal	*I4/amd*	*tI16*
B_h	WC	Hexagonal	*P6/mmm*	*hP2*
B_i	γ '-MoC	Hexagonal	*$P6_3/mmc$*	*hP8*
B_k	BN	Hexagonal	*$P6_3/mmc$*	*hP4*
B_l	AsS (Realgar)	Monoclinic	*$P2_1n$*	*mP32*
B_m	TiB	Orthorhombic	*Pnma*	*oP8*
B1	Halite, Rocksalt, NaCl	Cubic	*Fm3m*	*cF8*
B2	CsCl	Cubic	*Pm3m*	*cP2*
B3	ZnS (Sphalerite)	Cubic	*F43m*	*cF8*
B4	ZnS (Wurtzite)	Hexagonal	*$P6_3mc$*	*hP4*
$B8_1$	α-NiAs	Hexagonal	*$P6_3/mmc$*	*hP4*
$B8_2$	β-Ni_2In	Hexagonal	*$P6_3/mmc$*	*hP4*
B9	HgS (Cinnabar)	Hexagonal	*$P3_121$*	*hP6*
B10	LiOH (Lithine)	Tetragonal	*P4/nmm*	*tP4*
B11	PbO (Massicot)	Tetragonal	*P4/nmm*	*tP4*
B12	BN	Hexagonal	*$P6_3mc$*	*hP4*
B13	NiS (Millerite)	Hexagonal	*R3m*	*hR6*
B16	GeS	Orthorhombic	*Pnma*	*oP8*
B17	PtS (Cooperite)	Tetragonal	*$P4_2/mmc$*	*tP4*
B18	CuS (Covellite)	Hexagonal	*$P6_3/mmc$*	*hP12*
B19	AuCd	Orthorhombic	*Pmcm*	*oP4*
B20	FeSi	Cubic	*$P2_13$*	*cP8*
B21	CO	Cubic	*$P2_13$*	*cP8*
B24	TlF	Orthorhombic	*Fmmm*	*oF8*
B26	CuO	Monoclinic	*n.a.*	*n.a.*
B27	FeB	Orthorhombic	*Pbnm*	*oP8*
B29	SnS	Orthorhombic	*Pmcn*	*oP8*
B31	MnP	Orthorhombic	*Pbnm*	*oP8*
B32	NaTl	Cubic	*Fd3m*	*cF16*
B33	CrB	Orthorhombic	*Cmcm*	*oC8*
B34	PdS	Tetragonal	*$P4_2/m$*	*tP16*
B35	CoSn	Hexagonal	*P6/mmm*	*hP6*
B37	TlSe	Tetragonal	*I4/mcm*	*tI16*

Table D.10. Strukturbericht designations for ternary compounds (A_2X or AX_2 type)

Designation	Typical example (Mineral name)	Crystal system	Hermann–Mauguin	Pearson's
C_a	Mg_2Ni	Hexagonal	*$P6_222$*	*hP18*
C_b	Mg_2Cu	Orthorhombic	*Fddd*	*oF48*
C_c	$ThSi_2$	Tetragonal	*I4/amd*	*tI12*
C_e	$CoGe_2$	Orthorhombic	*Aba*	*oA24*
C_g	ThC_2	Monoclinic	*C2/c*	*mC12*
C_h	Cu_2Te	Hexagonal	*P6/mmm*	*hP6*
C_k	$LiZn_2$	Hexagonal	*$P6_3/mmc$*	*hP3*
C_1	CaF_2 (Fluorite)	Cubic	*Fm3m*	*cF12*
$C1_b$	MgAgAs	Cubic	*F43m*	*cF12*
C2	FeS_2 (Pyrite)	Cubic	*Pa3*	*cP12*
C3	Cu_2O (Cuprite)	Cubic	*Pn3m*	*cP6*
C4	TiO_2 (Rutile)	Tetragonal	*$P4_2/mmm$*	*tP6*
C5	TiO_2 (Anatase)	Tetragonal	*$I4_1/amd$*	*tI6*
C6	CdI_2	Hexagonal	*P3m1*	*hP3*
C7	MoS_2 (Molybdenite)	Hexagonal	*$P6_3/mmc$*	*hP6*
C8	SiO_2 (Quartz)	Hexagonal	*$R3_12_1$*	*hR9*
C9	SiO_2 (β-Cristoballite)	Cubic	*$P4_32_12$*	*cP12*
C10	SiO_2 (β-Tridymite)	Hexagonal	*$P6_3/mmc$*	*hP12*
$C11_a$	CaC_2	Tetragonal	*I4/mmm*	*tI6*
$C11_b$	$MoSi_2$	Tetragonal	*I4/mmm*	*tI6*
C12	$CaSi_2$	Rhombohedral	*R3m*	*hR6*
C14	$MgZn_2$ (Laves)	Hexagonal	*$P6_3/mmc$*	*hP12*
C15	$MgCu_2$(Laves)	Cubic	*Fd3m*	*cF24*
$C15_b$	$AuBe_5$	Cubic	*F43m*	*cF24*
C16	Al_2Cu	Tetragonal	*I4/mcm*	*tI12*
C18	FeS_2 (Marcassite)	Orthorhombic	*Pnnm*	*oP6*
C19	α-Sm	Hexagonal	*R3m*	*hR3*
C21	TiO_2, (Brookite)	Orthorhombic	*Pbca*	*oP24*
C22	Fe_2P	Hexagonal	*P26m*	*hP9*
C23	$PbCl_2$	Orthorhombic	*Pnma*	*oP12*
C24	$HgBr_2$	Orthorhombic	*$Cmc2_1$*	*oC12*
C25	$HgCl_2$	Orthorhombic	*Pnma*	*oP16*
C28	$HgCl_2$	Orthorhombic	*n.a.*	*n.a.*
C29	SrH_2	Orthorhombic	*n.a.*	*n.a.*
C32	AlB_2	Hexagonal	*P6/mmm*	*hP3*
C33	Bi_2Te_3S	Hexagonal	*R3m*	*hR5*
C34	$AuTe_2$ (Calaverite)	Monoclinic	*C2/m*	*mC6*
C35	$CaCl_2$	Orthorhombic	*n.a.*	*n.a.*
C36	$MgNi_2$	Hexagonal	*$P6_3/mmc$*	*hP24*
C37	Co_2Si	Orthorhombic	*Pbnm*	*oP12*
C38	Cu_2Sb	Tetragonal	*P4/nmm*	*tP6*
C40	$CrSi_2$	Hexagonal	*$P6_222$*	*hP9*

Table D.10. *(continued)*

Designation	Typical example (Mineral name)	Crystal system	Hermann–Mauguin	Pearson's
C42	SiS_2	Orthorhombic	*Icma*	*oI12*
C43	ZrO_2 (Baddeleyite)	Monoclinic	$P2_1c$	*mP12*
C44	GeS_2	Orthorhombic	*Fdd2*	*oF72*
C46	$AuTe_2$ (Krennerite)	Orthorhombic	*Pma2*	*oP24*
C49	$ZrSi_2$	Orthorhombic	*Cmcm*	*oC12*
C54	TiS_2	Orthorhombic	*Fddd*	*oF24*

Table D.11. Strukturbericht designations for quaternary compounds (A_3X or AX_3 type)

Designation	Typical example (Mineral name)	Crystal system	Hermann–Mauguin	Pearson's
$D0_a$	β-$TiCu_3$	Orthotrhombic	*Pmmn*	*oP8*
$D0_b$	γ-Ag_3Ga	Hexagonal	*P3*	*hP9*
$D0_c$	U_3Si	Tetragonal	*I4/mcm*	*tI16*
$D0_d$	Mn_3As	Orthorhombic	*Pmmn*	*oP16*
$D0_2$	$CoAs_3$ (Skutterudite)	Cubic	*Im3*	*cI32*
$D0_3$	BiF_3 or $BiLi_3$	Cubic	*Fm3m*	*cF16*
$D0_4$	$CrCl_3$	Hexagonal	$P3_112$	*hP24*
$D0_5$	BiI_3	Rhombohedral	*R3*	*hR8*
$D0_9$	ReO_3 or Cu_3N	Cubic	*Pm3m*	*cP4*
$D0_{11}$	Fe_3C	Orthorhombic	*Pnma*	*oP16*
DO_{14}	AlF_3	Rhombohedral	*R32*	*hR8*
DO_{15}	$AlCl_3$	Monoclinic	*C2/m*	*mC16*
$D0_{18}$	Na_3As	Hexagonal	$P6_3/mmc$	*hP8*
$D0_{19}$	Mg_3Cd	Hexagonal	$P6_3/mmc$	*hP8*
$D0_{20}$	$NiAl_3$	Orthorhombic	*Pnma*	*oP16*
$D0_{21}$	Cu_3P	Hexagonal	*P3c1*	*hP24*
$D0_{22}$	$TiAl_3$	Tetragonal	*I4/mmm*	*tI8*
$D0_{23}$	$ZrAl_3$	Tetragonal	*I4/mmm*	*tI16*
$D0_{24}$	$TiNi_3$	Hexagonal	$P6_3/mmc$	*hP16*

Table D.12. Strukturbericht designations for compounds (A_4X or AX_4 type)

Designation	Typical example (Mineral name)	Crystal system	Hermann–Mauguin	Pearson's
$D1_3$	$BaAl_4$	Tetragonal	*I4/mmm*	*tI10*
$D1_a$	$MoNi_4$	Tetragonal	*I4/m*	*tI10*
$D1_b$	UAl_4	Orthorhombic	*Imma*	*oI20*
$D1_c$	$PtSn_4$	Orthorhombic	*Aba2*	*oC20*
$D1_d$	$PtPb_4$	Tetragonal	*P4/nbm*	*tP10*
$D1_e$	UB_4	Tetragonal	*P4/mbm*	*tP20*
$D1_f$	Mn_4B	Orthorhombic	*Fddd*	*oF40*
$D1_g$	B_4C	Rhombohedral	*R3m*	*tR15*

Table D.13. Strukturbericht designations for other compounds

Designation	Typical example (Mineral name)	Crystal system	Hermann–Mauguin	Pearson's
$D2_a$	$TiBe_{12}$	Hexagonal	*P6/mmm*	*hP13*
$D2_b$	$ThMn_{12}$	Tetragonal	*I4/mcm*	*tI26*
$D2_c$	U_6Mn	Tetragonal	*I4/mcm*	*tI28*
$D2_d$	$CaCu_5$	Hexagonal	*C6/mmm*	*hC6*
$D2_e$	$BaHg_{11}$	Cubic	*Pm3m*	*cP36*
$D2_f$	UB_{12}	Cubic	*Fm3m*	*cF52*
$D2_g$	Fe_8N	Tetragonal	*I4/mmm*	*tI18*
$D2_h$	Al_6Mn	Orthorhombic	*Cmcm*	*oC28*
$D2_1$	CaB_6	Cubic	*Pm3m*	*cP7*
$D2_3$	$NaZn_{13}$	Cubic	*Fm3c*	*cF112*
$D5_a$	U_3Si_2	Tetragonal	*P4/mbm*	*tP10*
$D5_b$	Pt_2Sn_3	Hexagonal	*P6/mmc*	*hR10*
$D5_c$	Pu_2C_3	Cubic	*I43d*	*cI40*
$D5_e$	Ni_3Si_2	Rhombohedral	*R32*	*hR5*
$D5_1$	α-Al_2O_3	Rhombohedral	*R3c*	*hR10*
$D5_2$	La_2O_3	Hexagonal	*P3m1*	*hP5*
$D5_3$	Mn_2O_3	Cubic	*Ia3*	*cI80*
$D5_8$	Sb_2S_3	Orthorhombic	*Pbnm*	*oP20*
$D5_9$	Zn_3P_2	Tetragonal	*P4/nmc*	*tP40*
$D5_{10}$	Cr_3C_2	Orthorhombic	*Pbnm*	*oP20*
$D5_{13}$	Ni_2Al_3	Hexagonal	*C3m1*	*hC5*
$D5_{19}$	Al_3Ni_2			
$D7_a$	Ni_3Sn_4	Monoclinic	*C2/m*	*mC14*
$D7_b$	Ta_3B_4	Orthorhombic	*Immm*	*oI14*
$D7_1$	Al_4C_3	Rhombohedral	*R3m*	*hR7*
$D7_2$	Co_3S_4	Cubic	*Fd3m*	*cF56*
$D7_3$	Th_3P_4	Cubic	*I43d*	*cI26*
$D8_a$	Th_6Mn_{23}	Cubic	*Fm3m*	*cF116*
$D8_b$	V_3Ni_2	Tetragonal	*P4/mnm*	*tP30*
$D8_c$	$Mg_2Cu_6Al_5$	Cubic	*Pm3m*	*cP39*
$D8_d$	Co_2Al_9	Monoclinic	$P2_1/a$	*mP22*
$D8_e$	$Mg_{32}(Al, Zn)_{49}$	Cubic	*Im3m*	*cI162*
$D8_f$	Ir_3Sn_7	Cubic	*Im3m*	*cI40*
$D8_g$	Mg_5Ga_3	Orthorhombic	*Ibam*	*oI28*
$D8_h$	W_2B_5	Hexagonal	$P6_3/mmc$	*hP14*
$D8_i$	Mo_2B_5	Rhombohedral	*R3m*	*hR7*
$D8_k$	Th_7S_{12}	Hexagonal	$P6_3/m$	*hP19*
$D8_l$	Bi_3Cr_5	Tetragonal	*I4/mcm*	*tI32*
$D8_m$	Si_3W_5	Tetragonal	*I4/mcm*	*tI32*

Table D.13. *(continued)*

Designation	Typical example (Mineral name)	Crystal system	Hermann–Mauguin	Pearson's
$D8_1$	Fe_3Zn_{10}	Cubic	*Im3m*	*cI52*
$D8_2$	Cu_5Zn_8	Cubic	*I43m*	*cI52*
$D8_3$	Cu_9Al_4	Cubic	*P43m*	*cP52*
$D8_4$	$Cr_{23}C_6$	Cubic	*Fm3m*	*cF116*
$D8_5$	Fe_7W_6	Rhombohedral	*R3m*	*hR13*
$D8_6$	$Cu_{15}Si_4$	Cubic	*I43d*	*cI76*
$D8_8$	Mn_5Si_3	Hexagonal	$P6_3/mcm$	*hP16*
$D8_9$	Co_9S_8	Cubic	*Fm3m*	*cF68*
$D8_{10}$	Cr_5Al_8	Rhombohedral	*R3m*	*hR26*
$D8_{11}$	Co_2Al_5	Hexagonal	$P6_3/mcm$	*hP28*
$D10_1$	Cr_7C_3	Hexagonal	*P31c*	*hP80*
$D10_2$	Fe_3Th_7	Hexagonal	$P6_3/mcm$	*hP20*
$E0_1$	PbClF	Tetragonal	*P4/nmm*	*tP6*
$E0_7$	FeAsS	Monoclinic	$B2_1/d$	*mB24*
$E1_a$	$MgCuAl_2$	Orthorhombic	*Cmcm*	*oC16*
$E1_b$	$AuAgTe_4$ (Sylvanite)	Monoclinic	*P2/c*	*mP12*
$E1_1$	$CuFeS_2$(Chalcopyrite)	Tetragonal	*I42d*	*tI16*
$E2_1$	$CaTiO_3$ (Perowskite)	Cubic	*Pm3m*	*cP5*
$E2_4$	Sn_2S_3	Orthorhombic	*Pnma*	*oP20*
E3	Al_2CdS_4	Tetragonal	*I4*	*tI14*
$E9_a$	Al_7Cu_2Fe	Tetragonal	*P4/mnc*	*tP40*
$E9_b$	$FeMg_3Al_8Si_6$	Hexagonal	*P62m*	*hP18*
$E9_c$	Mn_3Al_9Si	Hexagonal	$P6_3/mmc$	*hP26*
$E9_d$	$AlLi_3N_2$	Cubic	*Ia3*	*cI96*
$E9_e$	$CuFe_2S_3$ (Cubanite)	Orthorhombic	*Pnma*	*oP24*
$E9_3$	Fe_3W_3C	Cubic	*Fd3m*	*cF112*
$F0_1$	NiSSb (Ullmanite)	Cubic	$P2_13$	*cP12*
$F5_a$	$KFeS_2$	Monoclinic	*C2/c*	*mC16*
$F5_1$	$CrNaS_2$	Rhombohedral	*R3m*	*hR4*
$F5_6$	CuS_2Sb	Orthorhombic	*Pnma*	*oP16*
GO_6	$KClO_3$	Monoclinic	$P2_1/m$	*mP10*
$H1_1$	Al_2MgO_4 (Spinel)	Cubic	*Fd3m*	*cF56*
$H2_4$	Cu_3S_4V (Sulvanite)	Cubic	*P43m*	*cP8*
$H2_5$	$AsCu_3S_4$ (Enargite)	Orthorhombic	$Pmn2_1$	*oP16*
$H2_6$	$FeCu_2SnS_4$ (Stannite)	Tetragonal	*I42m*	*tI16*
$L1_a$	Pt_3Cu	Cubic	*Fm3c*	*cF32*
$L1_0$	CuAu	Tetragonal	*C4/mmm*	*tC4*
$L1_2$	Cu_3Au	Cubic	*Pm3m*	*cP4*
$L2_a$	δ-TiCu	Tetragonal	*P4/mmm*	*tP2*

Table D.13. *(continued)*

Designation	Typical example (Mineral name)	Crystal system	Hermann–Mauguin	Pearson's
$L2_1$	$AlCu_2Mn$	Cubic	*Fm3m*	*cF16*
$L2_2$	Sb_2Tl_7	Cubic	*Im3m*	*cI54*
L'_1	Fe_4N	Cubic	*Pm3m*	*cP5*
L'_2	Martensite	Tetragonal	*I4/mmm*	*tI3*
$L'2_b$	ThH_2	Tetragonal	*I4/mmm*	*tI6*
L'3	Fe_2N	Hexagonal	$P6_3/mmc$	*hP3*
$L'6_0$	$CuTi_3$	Tetragonal	*P4/mmm*	*tP4*
L'6	no name	Tetragonal	*F4/mmm*	*tF4*

D.9 The 230 Space Groups

Table D.14. Triclinic space groups

Ordered number	Space group (Hermann–Mauguin)
001	*P 1*
002	*P 1*

Table D.15. Monoclinic space groups

Ordered number	Space group (Hermann–Mauguin)
003	*P 2*
004	$P\ 2_1$
005	*C 2*
006	*P m*
007	*P c*
008	*C m*
009	*C c*
010	*P 2/m*
011	$P\ 2_1/m$
012	*C 2/m*
013	*P 2/c*
014	$P\ 2_1/c$
015	*C 2/c*

Table D.16. Orthorhombic space groups

Ordered number	Space group (Hermann–Mauguin)
016	$P\,2\,2\,2$
017	$P\,2\,2\,2_1$
018	$P\,2_1\,2_1\,2$
019	$P\,2_1\,2_1\,2_1$
020	$C\,2\,2\,2_1$
021	$C\,2\,2\,2$
022	$F\,2\,2\,2$
023	$I\,2\,2\,2$
024	$I\,2_1\,2_1\,2_1$
025	$P\,m\,m\,2$
026	$P\,m\,c\,2_1$
027	$P\,c\,c\,2$
028	$P\,m\,a\,2$
029	$P\,c\,a\,2_1$
030	$P\,n\,c\,2$
031	$P\,m\,n\,2_1$
032	$P\,b\,a\,2$
033	$P\,n\,a\,2_1$
034	$P\,n\,n\,2$
035	$C\,m\,m\,2$
036	$C\,m\,c\,2_1$
037	$C\,c\,c\,2$
038	$A\,m\,m\,2$
039	$A\,b\,m\,2$
040	$A\,m\,a\,2$
041	$A\,b\,a\,2$
042	$F\,m\,m\,2$
043	$F\,d\,d\,2$
044	$I\,m\,m\,2$
045	$I\,b\,a\,2$
046	$I\,m\,a\,2$
047	$P\,m\,m\,m$
048	$P\,n\,n\,n$
049	$P\,c\,c\,m$
050	$P\,b\,a\,n$
051	$P\,m\,m\,a$
052	$P\,n\,n\,a$
053	$P\,m\,n\,a$
054	$P\,c\,c\,a$

Table D.16. *(continued)*

Ordered number	Space group (Hermann–Mauguin)
055	*P b a m*
056	*P c c n*
057	*P b c m*
058	*P n n m*
059	*P m m n*
060	*P b c n*
061	*P b c a*
062	*P n m a*
063	*C m c m*
064	*C m c a*
065	*C m m m*
066	*C c c m*
067	*C m m a*
068	*C c c a*
069	*F m m m*
070	*F d d d*
071	*I m m m*
072	*I b a m*
073	*I b c a*
074	*I m m a*

Table D.17. Tetragonal space groups

Ordered number	Space group (Hermann–Mauguin)
075	$P\ 4$
076	$P\ 4_1$
077	$P\ 4_2$
078	$P\ 4_3$
079	$I\ 4$
080	$I\ 4_1$
081	$P\ 4$
082	$I\ 4$
083	$P\ 4/m$
084	$P\ 4_2/m$
085	$P\ 4/n$
086	$P\ 4_2/n$
087	$I\ 4/m$
088	$I\ 4_1/a$

Table D.17. *(continued)*

Ordered number	Space group (Hermann–Mauguin)
089	$P\ 4\ 2\ 2$
090	$P\ 4\ 2_1\ 2$
091	$P\ 4_1\ 2\ 2$
092	$P\ 4_1\ 2_1\ 2$
093	$P\ 4_2\ 2\ 2$
094	$P\ 4_2\ 2_1\ 2$
095	$P\ 4_3\ 2\ 2$
096	$P\ 4_3\ 2_1\ 2$
097	$I\ 4\ 2\ 2$
098	$I\ 4_1\ 2\ 2$
099	$P\ 4\ m\ m$
100	$P\ 4\ b\ m$
101	$P\ 4_2\ c\ m$
102	$P\ 4_2\ n\ m$
103	$P\ 4\ c\ c$
104	$P\ 4\ n\ c$
105	$P\ 4_2\ m\ c$
106	$P\ 4_2\ b\ c$
107	$I\ 4\ m\ m$
108	$I\ 4\ c\ m$
109	$I\ 4_1\ m\ d$
110	$I\ 4_1\ c\ d$
111	$P\ 4\ 2\ m$
112	$P\ 4\ 2\ c$
113	$P\ 4\ 2_1\ m$
114	$P\ 4\ 2_1\ c$
115	$P\ 4\ m\ 2$
116	$P\ 4\ c\ 2$
117	$P\ 4\ b\ 2$
118	$P\ 4\ n\ 2$
119	$I\ 4\ m\ 2$
120	$I\ 4\ c\ 2$
121	$I\ 4\ 2\ m$
122	$I\ 4\ 2\ d$
123	$P\ 4/m\ m\ m$
124	$P\ 4/m\ c\ c$
125	$P\ 4/n\ b\ m$
126	$P\ 4/n\ n\ c$
127	$P\ 4/m\ b\ m$

Table D.17. *(continued)*	
Ordered number	Space group (Hermann–Mauguin)
128	*P 4/m n c*
129	*P 4/n m m*
130	*P 4/n c c*
131	$P\ 4_2/m\ m\ c$
132	$P\ 4_2/m\ c\ m$
133	$P\ 4_2/n\ b\ c$
134	$P\ 4_2/n\ n\ m$
135	$P\ 4_2/m\ b\ c$
136	$P\ 4_2/m\ n\ m$
137	$P\ 4_2/n\ m\ c$
138	$P\ 4_2/n\ c\ m$
139	*I 4/m m m*
140	*I 4/m c m*
141	$I\ 4_1/a\ m\ d$
142	$I\ 4_1/a\ c\ d$

Table D.18. Trigonal space groups	
Ordered number	Space group (Hermann–Mauguin)
143	*P 3*
144	$P\ 3_1$
145	$P\ 3_2$
146	*R 3*
147	*P 3*
148	*R 3*
149	*P 31 2*
150	$P\ 3\ 2\ _1$
151	$P\ 3_1\ 1\ 2$
152	$P\ 3_1\ 2 1$
153	$P\ 32\ _1\ 2$
154	$P\ 32\ 2_1$
155	*R 3 2*
156	*P 3 m 1*
157	*P 3 1 m*
158	*P 3 c 1*
159	*P 3 1 c*
160	*R 3 m*
161	*R 3 c*

Appendix D

Table D.18. *(continued)*

Ordered number	Space group (Hermann–Mauguin)
162	*P 3 1 m*
163	*P 3 1 c*
164	*P 3 m 1*
165	*P 3 c 1*
166	*R 3 m*
167	*R 3 c*

Table D.19. Hexagonal space groups

Ordered number	Space group (Hermann–Mauguin)
168	$P\ 6$
169	$P\ 6_1$
170	$P\ 6_5$
171	$P\ 6_2$
172	$P\ 6_4$
173	$P\ 6_3$
174	$P\ 6$
175	$P\ 6/m$
176	$P\ 6_3/m$
177	$P\ 6\ 2\ 2$
178	$P\ 6_1\ 2\ 2$
179	$P\ 6_5\ 2\ 2$
180	$P\ 6_2\ 2\ 2$
181	$P\ 6_4\ 2\ 2$
182	$P\ 6_3\ 2\ 2$
183	$P\ 6\ m\ m$
184	$P\ 6\ c\ c$
185	$P\ 6_3\ c\ m$
186	$P\ 6_3\ m\ c$
187	$P\ 6\ m\ 2$
188	$P\ 6\ c\ 2$
189	$P\ 6\ 2\ m$
190	$P\ 6\ 2\ c$
191	$P\ 6/m\ m\ m$
192	$P\ 6/m\ c\ c$
193	$P\ 6_3/m\ c\ m$
194	$P\ 6_3/m\ m\ c$

Table D.20. Cubic space groups

Ordered number	Space group (Hermann–Mauguin)
195	*P 2 3*
196	*F 2 3*
197	*I 2 3*
198	$P\ 2_1\ 3$
199	$I\ 2_1\ 3$
200	*P m 3*
201	*P n 3*
202	*F m 3*
203	*F d 3*
204	*I m 3*
205	*P a 3*
206	*I a3*
207	*P 4 3 2*
208	$P\ 4_2\ 3\ 2$
209	*F 4 3 2*
210	$F\ 4_1\ 3\ 2$
211	*I 4 3 2*
212	$P\ 4_3\ 3\ 2$
213	$P\ 4_1\ 3\ 2$
214	$I\ 4_1\ 3\ 2$
215	*P 4 3 m*
216	*F 4 3 m*
217	*I 4 3 m*
218	*P 4 3 n*
219	*F 4 3 c*
220	*I 4 3 d*
221	*P m 3 m*
222	*P n 3 n*
223	*P m 3 n*
224	*P n 3 m*
225	*F m 3 m*
226	*F m 3 c*
227	*F d 3 m*
228	*F d 3 c*
229	*I m 3 m*
230	*I a 3 d*

D.10 Crystallographic Calculations

D.10.1 Theoretical Crystal Density

The theoretical density, ρ, expressed in $kg.m^{-3}$, of a crystal having a number Z of entities with atomic (or molecular) molar mass M, expressed in $kg.mol^{-1}$, placed in a space lattice structure having a unit cell of volume V, expressed in m^3 is given by the following equation, where N_A is Avogadro's number (i.e., 6.0221367×10^{23} mol^{-1}) :

$$\rho_{\text{theoretical}} = Z \cdot M / N_A \cdot V_{\text{cell}}$$

D.10.2 Lattice Point and Vector Position

A lattice point, {M}, which describes the position of a microscopic entity (e.g., electrons, ions, atoms, molecules or clusters), is located in the crystal space lattice by giving the number of unit translations, along each of the three distinct translation directions, by which it is displaced from the point {O} as fixed origin. Therefore, each lattice point is entirely described by a set of three coordinates (u, v, w) or by the single position vector $\boldsymbol{V}$:

$$\boldsymbol{V} = \mathbf{OM} = u \cdot \boldsymbol{a} + v \cdot \boldsymbol{b} + w \cdot \boldsymbol{c}$$

NB: Sometimes the lattice point coordinates are denoted by the designation: $\cdot\ uvw \cdot$, (e.g. $\cdot$ 320 $\cdot$)

D.10.3 Scalar Product

The scalar product between two vectors is a scalar quantity represented as $\boldsymbol{V}_1 \cdot \boldsymbol{V}_2$ and is defined by the following equation:

$$\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = |\boldsymbol{V}_1| \cdot |\boldsymbol{V}_2| \cos(\boldsymbol{V}_1, \boldsymbol{V}_2) = |\boldsymbol{V}_1| \cdot |\boldsymbol{V}_2| \cos\theta$$

where θ is the plane angle measured counterclockwise between the two vectors and expressed in radians. Introducing the set of six vector coordinates, it is possible to express the scalar product analytically as:

$$\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = [u_1 u_2 \boldsymbol{a}^2 + v_1 v_2 \boldsymbol{b}^2 + w_1 w_2 \boldsymbol{c}^2 + (u_1 v_2 + v_1 u_2)\boldsymbol{ab}\cos\gamma + (u_1 w_2 + w_1 u_2)\boldsymbol{ac}\cos\beta \\ + (w_1 v_2 + v_1 w_2)\boldsymbol{bc}\cos\alpha]$$

Finally, the scalar product can be also written as a matrix product:

$$\boldsymbol{V}_1 \cdot \boldsymbol{V}_2 = (u_1 v_1 w_1) \cdot \begin{vmatrix} \boldsymbol{a}\cdot\boldsymbol{a} & \boldsymbol{a}\cdot\boldsymbol{b} & \boldsymbol{a}\cdot\boldsymbol{c} \\ \boldsymbol{b}\cdot\boldsymbol{a} & \boldsymbol{b}\cdot\boldsymbol{b} & \boldsymbol{b}\cdot\boldsymbol{c} \\ \boldsymbol{c}\cdot\boldsymbol{a} & \boldsymbol{c}\cdot\boldsymbol{b} & \boldsymbol{c}\cdot\boldsymbol{c} \end{vmatrix} \cdot \begin{vmatrix} u_2 \\ v_2 \\ w_2 \end{vmatrix}$$

D.10.4 Vector or Cross Product

The vector product between two vectors is a vector quantity represented as $\boldsymbol{V}_1 \times \boldsymbol{V}_2$ or $\boldsymbol{V}_1 \wedge \boldsymbol{V}_2$ and is defined by the following equation:

$$\boldsymbol{V}_1 \times \boldsymbol{V}_2 = |\boldsymbol{V}_1| \times |\boldsymbol{V}_2| \sin(\boldsymbol{V}_1, \boldsymbol{V}_2) = |\boldsymbol{V}_1| \times |\boldsymbol{V}_2| \sin\theta$$

where θ is the plane angle measured counterclockwise between the two vectors and expressed in radians. Introducing the set of the six vector coordinates, it is possible to express the vector product analytically as:

$$\boldsymbol{V}_1 \times \boldsymbol{V}_2 = [(v_1 w_2 - w_1 v_2)\, \boldsymbol{b} \times \boldsymbol{c} + (u_2 w_1 - u_1 w_2)\, \boldsymbol{c} \times \boldsymbol{a} + (u_1 v_2 - u_2 v_1) \boldsymbol{a} \times \boldsymbol{b}]$$

Finally, the vector product can also be written as a matrix determinant:

$$\boldsymbol{V}_1 \times \boldsymbol{V}_2 = \begin{vmatrix} \boldsymbol{a} & \boldsymbol{b} & \boldsymbol{c} \\ u_1 & v_1 & w_1 \\ u_2 & v_2 & w_2 \end{vmatrix}$$

D.10.5 Mixed Product and Cell Multiplicity

The mixed product between three vectors is a scalar quantity represented as $(\boldsymbol{V}_1, \boldsymbol{V}_2, \boldsymbol{V}_3)$ and is defined to be equal to:

$$\boldsymbol{V}_1 \cdot (\boldsymbol{V}_2 \times \boldsymbol{V}_3) = (\boldsymbol{V}_1 \times \boldsymbol{V}_2) \cdot \boldsymbol{V}_3$$

The vector product can also be written as a matrix product:

$$(\boldsymbol{V}_1, \boldsymbol{V}_2, \boldsymbol{V}_3) = \begin{vmatrix} \underbrace{\begin{matrix} u_1 & v_1 & w_1 \\ u_2 & v_2 & w_2 \\ u_3 & v_3 & w_3 \end{matrix}}_{\text{cell multiplicity}} \end{vmatrix} (\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c})$$

The ***multiplicity of the cell,*** m, is a dimensionless physical quantity equal to the number of entities (e.g., electrons, ions, atoms, molecules) contained in the crystal lattice structure.

Table D.21. Cell multiplicity

Class	Multiplicity	Name
Single unit cell	$m = 1$	primitive cell
Multiple cell	$m = 2$	double cell
	$m = 3$	triple cell
	$m = 4$	quadruple cell

Important note: The rigorous deduction of entities (e.g., ions, atoms, molecules) contained inside the unit cell only depends on their particular locations in the crystal space lattice so that,

(i) Entities located on the corners are counted as one eight (1/8), because they are shared by eight other neighboring cells.

(ii) Entities located on the edges of the lattice are counted as one quarter (1/4) because they are shared by four neighboring cells.

(iii) Entities located at the faces of the cell are counted as half (1/2) because they are shared by two adjacent cells.

(iv) Entities located inside the cell space lattice are counted as unity (1).

Therefore the multiplicity, m, of the cell can be easily calculated from the number, N, of entities in each particular location (i.e., corners, edges, faces, interior):

$$m = N_{\text{inside}} + N_{\text{faces}}/2 + N_{\text{edges}}/4 + N_{\text{corners}}/8$$

D.10.6 Unit Cell Volume

The unit cell volume is given by the following general equation which is calculated from the mixed product of the three lattice vectors:

$$V_{\text{unit cell}} = (\mathbf{a}, \mathbf{b}, \mathbf{c}) = abc\,(1-\cos^2\alpha-\cos^2\beta-\cos^2\gamma+2\cos\alpha\cos\beta\cos\gamma)^{1/2}$$

Table D.22. Space lattice volume

System	Volume
Cubic	$V_C = a^3$
Tetragonal	$V_Q = a^2c$
Hexagonal	$V_H = a^2c\sqrt{3}/2 = 0.866a^2c$
Rhomboedral	$V_R = a^3(1-3\cos^2\alpha+2\cos^3\alpha)^{1/2}$
Orthorhombic	$V_O = abc$
Monoclinc	$V_M = abc\sin\beta$
Triclinic	$V_T = abc\,(1-\cos^2\alpha-\cos^2\beta-\cos^2\gamma+2\cos\alpha\cos\beta\cos\gamma)^{1/2}$

D.10.7 Plane Angle between Lattice Planes

One is also occasionally interested in computing the angle between planes. If φ is the angle between the plane with Miller indices (h_1, k_1, l_1) and the plane with Miller indices (h_2, k_2, l_2), then the basic equation to calculate this angle is (see coefficients s_{ii} in Table D.24):

$$\cos\varphi = \frac{d_{h_1k_1l_1}\cdot d_{h_2k_2l_2}}{v^2}\left[s_{11}h_1h_2 + s_{22}k_1k_2 + s_{33}l_1l_2 + s_{23}\left(k_1l_2+k_2l_1\right) + s_{13}\left(l_1h_2+l_2h_1\right) + s_{12}\left(h_1k_2+h_2k_1\right)\right]$$

Table D.23. Plane angle between lattice planes

System	Plane angle
Cubic	$\cos\varphi = \dfrac{h_1h_2+k_1k_2+l_1l_2}{\sqrt{\left(h_1^2+k_1^2+l_1^2\right)\left(h_2^2+k_2^2+l_2^2\right)}}$
Tetragonal	$\cos\varphi = \dfrac{\dfrac{h_1h_2+k_1k_2}{a^2}+\dfrac{l_1l_2}{c^2}}{\sqrt{\left(\dfrac{h_1^2+k_1^2}{a^2}+\dfrac{l_1^2}{c^2}\right)\left(\dfrac{h_2^2+k_2^2}{a^2}+\dfrac{l_2^2}{c^2}\right)}}$
Hexagonal	$\cos\varphi = \dfrac{h_1h_2+k_1k_2+\dfrac{h_1k_2+h_2k_1}{2}+\dfrac{3a^2l_1l_2}{4c^2}}{\sqrt{\left(h_1^2+k_1^2+h_1k_1+\dfrac{3a^2l_1^2}{4c^2}\right)\left(h_2^2+k_2^2+h_2k_2+\dfrac{3a^2l_2^2}{4c^2}\right)}}$

Table D.23. *(continued)*

System	Plane angle
Rhomboedral	$\cos\varphi = \dfrac{(h_1h_2+k_1k_2+l_1l_2)(\sin\alpha)^2+(k_1l_2+k_2l_1+l_1h_2+l_2h_1+h_1k_2+k_1h_2)\left[(\cos\alpha)^2-\cos\alpha\right]}{\sqrt{\left[(h_1^2+k_1^2+l_1^2)(\sin\alpha)^2+2(h_1k_1+k_1l_1+h_1l_1)\right]\left[(\cos\alpha)^2-\cos\alpha\right]\left[(h_2^2+k_2^2+l_2^2)(\sin\alpha)^2+(2h_2k_2+k_2l_2+h_2l_2)\right]\left[(\cos\alpha)^2-\cos\alpha\right]}}$
Orthorhombic	$\cos\varphi = \dfrac{\frac{h_1h_2}{a^2}+\frac{k_1k_2}{b^2}+\frac{l_1l_2}{c^2}}{\sqrt{\left(\frac{h_1^2}{a^2}+\frac{k_1^2}{b^2}+\frac{l_1^2}{c^2}\right)\left(\frac{h_2^2}{a^2}+\frac{k_2^2}{b^2}+\frac{l_2^2}{c^2}\right)}}$
Monoclinc	$\cos\varphi = \dfrac{\frac{h_1h_2}{a^2}+\frac{k_1k_2(\sin\beta^2)}{b^2}+\frac{l_1l_2}{c^2}-\frac{(h_2l_1+h_1l_2)\cos\beta}{ac}}{\sqrt{\left[\frac{h_1^2}{a^2}+\frac{k_1^2(\sin\beta^2)}{b^2}+\frac{l_1^2}{c^2}-\frac{2h_1l_1\cos\beta}{ac}\right]\left[\frac{h_2^2}{a^2}+\frac{k_2^2(\sin\beta^2)}{b^2}+\frac{l_2^2}{c^2}-\frac{2h_2l_2\cos\beta}{ac}\right]}}$
Triclinic	see general formula

D.11 Interplanar Spacing

Table D.24. General formula of the interplanar spacing

$(1/d_{hkl}) = (1/V)\cdot(s_{11}\cdot h^2 + s_{22}\cdot k^2 + s_{33}\cdot l^2 + 2s_{12}\cdot hk + 2s_{23}\cdot kl + 2s_{13}\cdot hl)^{1/2}$ with $V = abc\cdot(1 - \cos^2\alpha - \cos^2\beta - \cos^2\gamma + 2\cos\alpha\cos\beta\cos\gamma)^{1/2}$	
$s_{11} = b^2c^2\sin^2\alpha$	$s_{12} = abc^2(\cos\alpha\cos\beta - \cos\gamma)$
$s_{22} = a^2c^2\sin^2\beta$	$s_{23} = a^2bc(\cos\beta\cos\gamma - \cos\alpha)$
$s_{33} = a^2b^2\sin^2\gamma$	$s_{31} = ab^2c(\cos\gamma\cos\alpha - \cos\beta)$

Table D.25. Interplanar spacing according to the type of crystal lattice

System	Interplanar spacing
Cubic	$\dfrac{1}{d_{hkl}} = \sqrt{\dfrac{h^2+k^2+l^2}{a^2}}$
Tetragonal	$\dfrac{1}{d_{hkl}} = \sqrt{\dfrac{h^2+k^2}{a^2}+\dfrac{l^2}{c^2}}$
Hexagonal	$\dfrac{1}{d_{hkl}} = \sqrt{\dfrac{4(k^2+hk+k^2)}{3a^2}+\dfrac{l^2}{c^2}}$
Rhombohedral	$\dfrac{1}{d_{hkl}} = \sqrt{\dfrac{(h^2+k^2+l^2)(\sin\alpha)^2+2(kh+kl+lh)(\cos\alpha^2-\cos\alpha)}{a\left[1-3(\cos\alpha)^2+2(\cos\alpha)^3\right]}}$

Table D.26. *(continued)*

System	Interplanar spacing
Orthorhombic	$\frac{1}{d_{hkl}}=\sqrt{\frac{h^2}{a^2}+\frac{k^2}{b^2}+\frac{l^2}{c^2}}$
Monoclinc	$\frac{1}{d_{hkl}}=\sqrt{\frac{h^2}{a^2(\sin\beta)^2}+\frac{k^2}{b^2(\sin\beta)^2}+\frac{l^2}{c^2(\sin\beta)^2}-\frac{2hl\cos\beta}{ac(\sin\beta)^2}}$
Triclinic	see general formula

D.12 Reciprocal Lattice Unit Cell

Table D.27. Definition of the reciprocal lattice

The three reciprocal lattice vectors are ***a****, ***b****, and ***c**** defined by the nine relations below

a.a* = 1	***b.a**** = 0	***c.a**** = 0
a.b* = 0	***b.b**** = 1	***c.b**** = 0
a.c* = 0	***b.c**** = 0	***c.c**** = 1

Note: A condensed notation used by crystallographers is as follows: $\mathbf{a}_i.\mathbf{b}_i = \delta_{ii}$, where δ_{ii} is the Kronecker operator (i.e., for i = j, δ_{ii} =1 and for i ≠ j, δ_{ii} =0). On the other hand, a slightly different notation is used in solid state physics: $\mathbf{a}_i.\mathbf{b}_j = 2\pi\delta_{ij}$.

E Transparent Materials for Optical Windows

Table E.1. Optical properties of window materials

Window material	Long (IR) and short (UV) cutt-offs						Refractive Index (n_D)	Comments
	Wavelength range (λ/µm)		Wavenumber range (σ/cm^{-1})		Colour temperature (T/K)			
LiF (lithium fluoride)	0.105	5.88	95000	1700	27531	493	1.40	Best VUV transmitter available
MgF_2 (Irtran-1)	0.115	8.00	87000	1250	25213	362	1.35	
SiO_2 (fused silica)	0.120	4.50	83333	2222	24150	644		
CaF_2 (fluorite; Irtran-3)	0.130	9.01	77000	1110	22315	322	1.434	Resists most acids and alkalis; withstands high pressure; insoluble in water.
Al_2O_3 (sapphire)	0.140	6.50	71429	1538	20700	446	1.765	Hard crystal
BaF_2 (barium fluoride)	0.149	13.51	67000	740	19417	214	1.46	Brittle crystal; insoluble in water; good resistance to fluorine and fluorides.
SiO_2 (quartz)	0.154	3.70	65000	2700	18837	782	1.549	Hard crystal transparent in the visible range
$CaCO_3$ (calcite)	0.200	5.50	50000	1818	14490	527	1.572	
KCl (sylvite)	0.210	30.00	47619	333	13800	97	1.490	
CsI (cesium iodide)	0.250	80.00	40000	125	11592	36	1.74	Soft crystal; soluble in water; hydroscopic; offers an extended transmission range.
C (diamond)	0.250	80.00	40000	125	11592	36	2.418	Phonon bands around 1900–2600 except in Type IIa diamonds, very useful for high-pressure or corrosive work.

Table E.1. *(continued)*

Window material	Long (IR) and short (UV) cutt-offs						Refractive Index (n_D)	Comments
	Wavelength range (λ/μm)		Wavenumber range (σ/cm^{-1})		Colour temperature (T/K)			
KBr (potassium bromide)	0.250	25.00	40000	400	11592	116	1.53	Very soft water soluble crystal; low cost and good transmission range; fogs.
KI (potassium iodide)	0.250	45.00	40000	222	11592	64		
NaCl (halite)	0.250	17.00	40000	588	11592	170	1.544	Very soft water soluble crystal; low cost and good transmission range; fogs.
PbF_2 (lead fluoride)	0.250	16.00	40000	625	11592	181		
CsBr (cesium bromide)	0.300	55.00	33333	182	9660	53		
Pyrex (Corning 7740)	0.333	2.50	30000	4000	8694	1159	1.47	
MgO (Irtran-5)	0.390	9.40	25641	1064	7431	308	1.735	
$SrTiO_3$ (strontium titanate)	0.390	6.80	25641	1471	7431	426		
AgCl (argyrite)	0.400	27.78	25000	360	7245	104	2.070	Soft crystal that is insoluble in water; darkens upon exposure to UV radiation; will cold flow.
TiO_2 (rutile)	0.430	6.20	23256	1613	6740	467	2.755	
ZnSe (Irtran-4)	0.450	21.80	22222	459	6440	133	2.890	Hard and brittle crystal; inert; ideal material for ATR.
AgBr (bromargyrite)	0.455	34.97	22000	286	6376	83	2.253	Soft crystal; insoluble in water; darkens upon exposure to UV radiation; will creep.
Tl_2BrI (KRS-5)	0.500	35.00	20000	286	5796	83	2.370	Toxic
$BaTiO_3$ (barium titanate)	0.500	7.50	20000	1333	5796	386		
CdS (cadmium sulfide)	0.500	16.00	20000	625	5796	181	2.320	
CdTe (Irtran-6)	0.500	25.00	20000	400	5796	116	2.670	Lower thermal conductity than ZnSe (used with CO2 lasers). Attacked by oxidizers.
K Tl Br-I (KRS-5)	0.500	40.00	20000	250	5796	72	2.37	Toxic; soft crystal deforms under pressure; good ATR material, soluble in bases and insoluble in acids, toxic.

Table E.1. *(continued)*

Window material	Long (IR) and short (UV) cutt-offs						Refractive Index (n_D)	Comments
	Wavelength range (λ/µm)		Wavenumber range (σ/cm^{-1})		Colour temperature (T/K)			
ZnS (Irtran-2)	0.570	14.70	17544	680	5084	197	2.356	Insoluble in water.
AsS_3 (glass)	0.600	13.00	16667	769	4830	223		
$MgAl_2O_4$ (spinel)	0.600	6.00	16667	1667	4830	483	1.719	
GeAsSe (amorphous)	0.909	16.00	11000	625	3188	181	2.50	AMTIR (Amorphous Material Transmitting IR) is a glass; insoluble in water; resistant to corrosion.
InP (indium phosphide)	1.000	14.00	10000	714	2898	207	3.100	
Se (amorphous selenium)	1.000	30.00	10000	333	2898	97	2.500	
Si (silicon)	1.200	16.67	8330	600	2414	174	3.490	Hard and brittle crystal; inert; ideal material for far-IR.
GaAs (gallium arsenide)	1.429	15.38	7000	650	2029	188	3.330	Hard crystal; can be made amorphous.
Ge (germanium)	1.818	23.00	5500	435	1594	126	3.990	Hard and brittle crystal; insoluble in water; well suited for ATR.
AsSeTe (amorphous)	2.500	11.11	4000	900	1159	261	2.80	Good for Mid-IR fiber optics; chemically inert.
Te (tellurium)	3.500	8.00	2857	1250	828	362	3.300	
Polyethylene (high-density)	16.000	300.00	625	33	181	10	1.54	Excellent for Far-IR; very cheap; attacked by few solvents; difficult to clean.

Irtran is a registered trademark of the Eastman Kodak Company
Transmission region at which a sample 2mm thick has 10% transmission

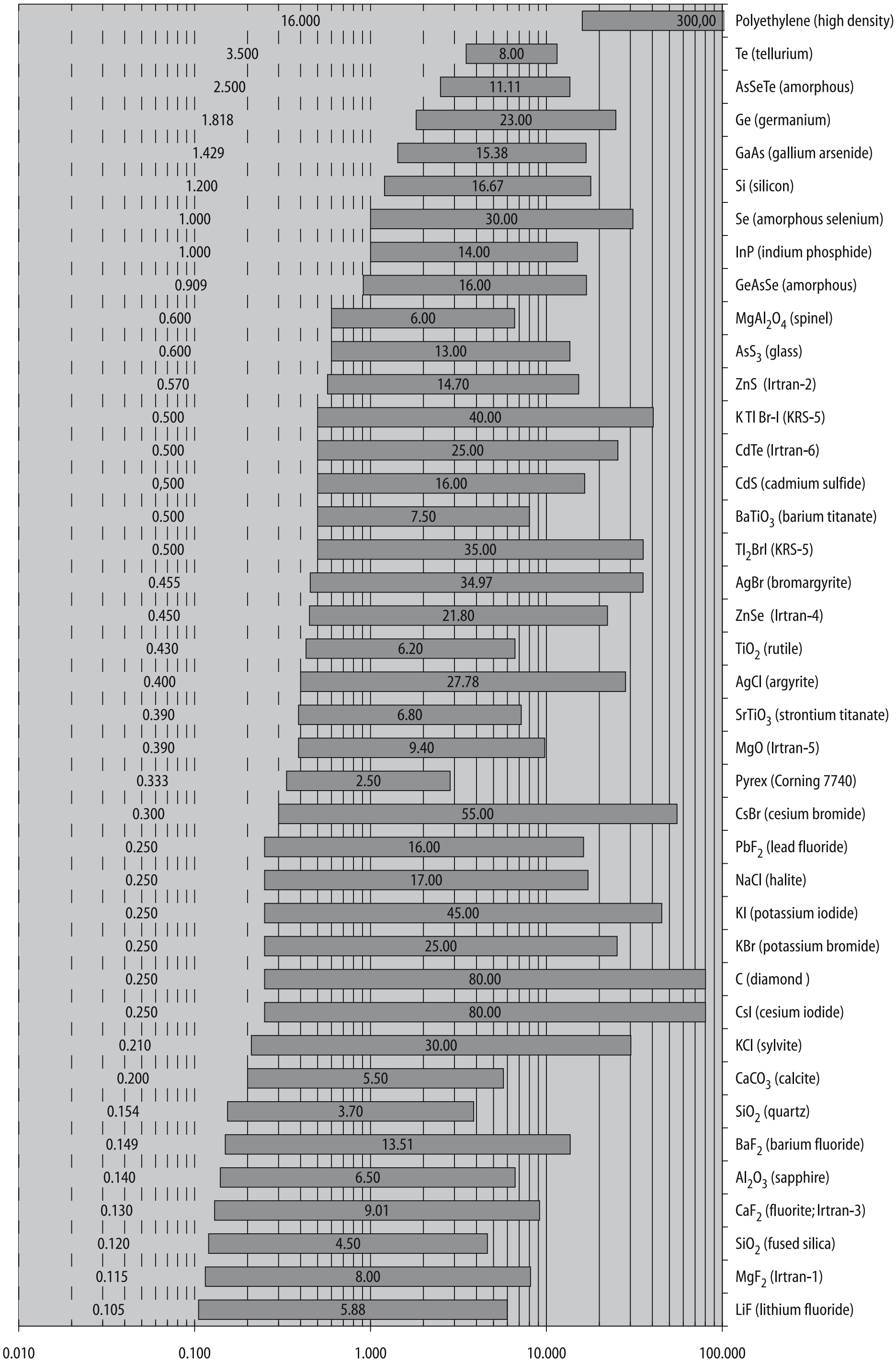

Figure E.1. Electromagnetic transparency range of optical window materials (micrometers)

F Corrosion Resistance of Materials Towards Various Corrosive Media

Table F.1. Maximum operating temperature (°C) of metals for handling liquid metals under inert atmosphere (A = Attacked)

Molten metal or alloy	Metallic container												
	316L	Ti	Zr	Hf	Nb	Ta	Mo	W	Ag	Au	Pt	Rh	Ir
Ag	n.a.	n.a.	n.a.	n.a.	n.a.	1200	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Al	A	750	n.a.	n.a.	n.a.	A	n.a.	n.a.	A	A	n.a.	n.a.	A
Bi	A	n.a.	n.a.	n.a.	n.a.	560	n.a.	n.a.	A	A	A	A	470
Ca	n.a.	n.a.	n.a.	n.a.	n.a.	1200	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	A
Cd	A	450	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	A
Ga	A	400	n.a.	n.a.	n.a.	400	400	n.a.	A	A	n.a.	n.a.	230
Hg	n.a.	150	n.a.	n.a.	n.a.	600	600	n.a.	A	A	A	550	550
In	A	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	A	n.a.	A	n.a.	360
K	1000	n.a.	600	600	n.a.	900	n.a.	n.a.	A	A	n.a.	260	260
Li	540	750	1000	1000	1000	1000	1200	1200	A	A	n.a.	n.a.	380
Mg	n.a.	850	A	A	1000	1150	n.a.	n.a.	A	A	n.a.	n.a.	A
Na	1000	600	600	600	n.a.	900	n.a.	n.a.	A	A	n.a.	290	290
NaK	n.a.	n.a.	600	600	n.a.	900	n.a.	n.a.	A	A	n.a.	n.a.	n.a.
Pb	n.a.	600	n.a.	n.a.	n.a.	1000	850	n.a.	A	A	A	A	n.a.
Sb	A	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Sn	A	600	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	A	n.a.	A	n.a.	n.a.
Th-Mg	n.a.	n.a.	n.a.	n.a.	850	1000	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
U	n.a.	n.a.	n.a.	n.a.	1400	1450	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Zn	A	750	A	A	450	500	n.a.	n.a.	A	A	n.a.	n.a.	A

Table F.2. Container material for handling molten salts, slags and fluxes

Molten salts	Material class	Resistant materials	Remarks
Molten chlorides	Pure metals	Gold (Au)	Inert (CO_2, N_2, Ar, He), oxidizing (air, O_2) or reducing (CO) atmosphere until 850°C. Creep behavior for thin walled crucibles
		Steel (Fe-0.8C)	Reducing or inert atmosphere (Ar, He) until 1200°C
		Platinum (Pt)	Inert (CO_2, N_2, Ar, He), oxidizing (air, O_2) or reducing (H_2) atmosphere until 1400°C. Avoid carbon.
		Molybdenum (Mo)	Vacuum, reducing or inert atmosphere (Ar, He) until 1600°C. Becomes brittle.
		Iridium (Ir)	Inert (CO_2, N_2, Ar, He), oxidizing (air, O_2) or reducing (CO) until 1800°C
	Glass	Borosilicated glass (Pyrex)	Dry and inert atmosphere (N_2, Ar, He) until 500°C
	Refractory and advanced ceramics	Fused silica (SiO_2)	Dry and inert atmosphere (N_2, Ar, He) until 1200°C
		Mullite ($Al_6Si_2O_{13}$)	Dry and inert atmosphere (N_2, Ar, He) until 1200°C
		Electrofused alumina (Al_2O_3)	Inert (CO_2, N_2, Ar, He), oxidizing (air, O_2) or reducing (CO) atmosphere even with water vapor until 1500°C
		Zirconia (ZrO_2, stabilized)	Inert (CO_2, N_2, Ar, He), oxidizing (air, O_2) or reducing (CO) atmosphere even with water vapor until 1600°C
		Boron nitride (HBN)	Dry and inert (CO_2, N_2, Ar, He) or oxidizing (air, O_2) atmosphere until 1500°C
	Carbon-based materials	Graphite	Reducing or inert atmosphere until 2000°C
		Vitreous carbon	Reducing or inert atmosphere until 1500°C. Oxidizing atmosphere until 600°C
Molten fluorides	Pure metals	Gold (Au)	Inert (CO_2, N_2, Ar, He), oxidizing (air, O_2) or reducing (CO) atmosphere until 850°C. Creep behavior for thin walled crucibles
		Nickel (Ni)	Reducing or inert atmosphere (Ar, He) until 1000°C
		Steel (Fe-0.8C)	Reducing or inert atmosphere (Ar, He) until 1200°C
		Platinum (Pt)	Inert (CO_2, N_2, Ar, He), oxidizing (air, O_2) or reducing (H_2) atmosphere until 1400°C. Avoid carbon.
		Molybdenum (Mo)	Reducing, vacuum or inert atmosphere (Ar, He) until 1600°C. Becomes brittle.
		Iridium (Ir)	Inert (CO_2, N_2, Ar, He), oxidizing (air, O_2) or reducing (CO) until 1800°C
	Refractory and advanced ceramics	Boron nitride (HBN)	Dry and inert (CO_2, N_2, Ar, He) or oxidizing (air, O_2) atmosphere until 1500°C
	Carbon-based materials	Graphite	Reducing or inert atmosphere until 2000°C
		Vitreous carbon	Reducing or inert atmosphere until 1500°C. Oxidizing until 600°C

Molten chloroaluminates	Refractory metals	Molybdenum (Mo), tungsten (W) and zirconium (Zr)	Inert atmosphere until 600°C
	Ceramics and glasses	Borosilicated glass (Pyrex)	Up to 230°C
		Vycor and fused silica	Until 600°C
		Vitreous carbon	Inert atmosphere until 600°C
Molten hydroxides	Noble and precious metals	Pure silver, gold, and platinum	Reducing atmosphere; usually corroded if oxidizing impurities are present such as nitrates. Melt resistance: Ag > Au> Pt.
	Nickel	Grade Ni 200	Reducing atmosphere and anhydrous melts. Protected by its passivation layer of NiO_2 which is insoluble.
	Refractory and advanced ceramics	Magnesia (MgO), beryllia (BeO) and zinc oxide (ZnO)	Suitable for basic melts only
		Electrofused alumina (Al_2O_3)	Suitable for acidic melts only
		Zirconia (ZrO_2)	Stable over the entire acidity range but sensitive to thermal shocks
		Glassy and impervious carbon	High temperature capabilities over the entire acidic range but damaged by liquid sodium; sensitive to mechanical stress upon cooling
	Polymers	Polytetrafluoroethylene (PTFE)	Suitable below 280°C but avoid the presence or formation of any trace of free alkali-metal. Perfect for the low melting point eutectic NaOH-KOH (170°C).
Molten titanates	Refractory metals	Molybdenum (Mo)	Vacuum, reducing or inert atmosphere (Ar, He) until 1800°C. Becomes brittle.
		Niobium (Nb)	Vacuum, reducing or inert atmosphere (Ar, He) until 1800°C.
		Iridium (Ir)	Inert (CO_2, N_2, Ar, He), oxidizing (air, O_2) or reducing (CO) until 2000°C.
		Tantalum (Ta)	Vacuum, reducing or inert atmosphere (Ar, He) until 2500°C.
		Tungsten (W)	Vacuum, reducing or inert atmosphere (Ar, He) until 2800°C.
Molten carbonates	Metals and alloys	Pure gold (Au)	Oxidizing atmosphere until 850°C. Completely immune towards molten alkali-carbonates.
		Pure aluminum	Can be used under oxidizing atmosphere util 600°C because it is protected by a $MAlO_2$ scale
		Gold-platinum	Oxidizing atmosphere util 700°C
		Austenitic stainless steel 304L	Oxidizing atmosphere until 500°C

Table F.2. *(continued)*

Molten salts	Material class	Resistant materials	Remarks
Molten carbonates	Metals and alloys	Austenitic stainless steel 310	Oxidizing atmosphere until 680°C
		Nickel-based alloys	Oxidizing atmosphere until 600°C
		High-chromium alloys	Oxidizing atmosphere until 700°C
	Ceramics	Electrofused alumina	Oxidizing atmosphere until 1000°C
		Graphite	Oxidizing atmosphere until 450°C
Molten nitrates	Metals	Platinum (Pt)	Below 400°C avoid the presence of peroxide anions.
	Ceramics	Electrofused alumina (Al_2O_3)	Below 400°C
	Polymers	Polytetrafluoroethylene (PTFE)	Suitable below 280°C with eutectic mixtures.
Molten sulfates	Metals	Pure iron (Fe)	
		Platinum (Pt)	
	Ceramics	Fused silica (SiO_2)	
Cryolite melts with dissolved aluminum metal	Advanced ceramics	Alumina (Al_2O_3)(*)	(*)Only in contact with alumina saturated melts (12 wt.% of dissolved Al_2O_3). Inert or oxidizing atmospheres until 1000°C.
		Boron nitride (HBN)	Inert atmosphere until 1000°C.
	Carbon-based materials	Graphite SGL grade R8710	Inert atmosphere until 1000°C. A layer of Al_4C_3 forms at the inner surface. Becomes fragile.
		Impervious carbon	Inert atmosphere until 1000°C . A layer of Al_4C_3 forms at the inner surface. Becomes fragile.

Table F.3. Maximum operating temperature (°C) of ceramics for handling liquid metals under inert atmosphere (A = Attacked)

Molten metal or alloy	Ceramic material								
	Pyrex	Fused silica (SiO_2)	Mullite ($Al_6Si_2O_{13}$)	Alumina (Al_2O_3)	Magnesia (MgO)	Spinel ($MgAl_2O_4$)	Zirconia (ZrO_2)	Beryllia (BeO)	Graphite (C)
Ag									1300
Al								1200	
Au						1897			1300
Bi									850
Ca									900
Cd	540								
Fe				1600	1550		1550	1550	
Ga	560	1100							
In	530	820							
K	335								
Mg									1300
Mn						1710			
Na									
Ni				1470			1470	1800	
Pb	520			1100		1400			800
Sb		850							850
Si				1890	1450				
Sn	285	590	1300	1830					910
Ti			A	A	1660	A	A	A	A (TiC)
Zn	510		1300						800

Table F.4. Corrosion rates of materials in hydrochloric acid and hydrogen chloride (HCl)[1]

Material class	Materials	Conc. and temp. range
Metals and Alloys	Carbon and low alloy steels	readily corroded
	Austenitic stainless steels (AISI 304, 316L)	readily corroded
	Nickel grade 200 and Monel® 400	resistant to dil. HCl <10 wt.%
	High-silicon cast iron (Durichlor®, 14.4 wt.% Si-3wt.% Mo) (not suitable with Fe^{3+}, Cu^{2+})	resistant to all conc. up to 95°C
	Duplex austenitic-ferritic stainless steel SAF 2540	resistant to dil. HCl < 3 wt.% up to 100°C
	Titanium alloy Ti-Pd (grades 7, 11) and Ti-Ru (grade 26, 28)	resistant with Fe(III) or Cu(II) acting as corrosion inhibitors

[1] Corrosion in the CPI: Corrosion by Hydrogen Chloride and Hydrochloric Acid – ASM International, Materials Park, OH (1994), pages 191–196 and 220–224.

Table F.4. *(continued)*

Material class	Materials	Conc. and temp. range
Metals and Alloys	Zircadyne® 702 (not suitable with Fe^{3+}, Cu^{2+})	resistant to all conc. up to b.p.
	Hastelloy® B2 (not suitable with Fe^{3+}, Cu^{2+})	resistant to all conc. up to b.p.
	Pure tantalum	resistant to 25 wt.% wt.% up to 190°C resistant to 37 wt.% up to 150°C
	Niobium and niobium zirconium	resistant to all conc. at RT
	Gold and Platinum	resistant to all conc. up to b.p.
Polymers and Elastomers	PE	resistant at room temperature
	PP	resistant to all conc. up to 110°C
	PVC	resistant to all conc. up to 110°C
	PVDC	resistant to all conc. up to 80°C
	PVDF (Kynar),	resistant to all conc. up to 135°C
	ECTFE (Halar)	resistant to 18 wt.% and 90°C
	Chlorobutyl elastomer	resistant to 20 wt.% at 90°C
	PTFE (Teflon)	resistant to all conc. up to 260°C
	Bromobutyl elastomer	resistant to 20 wt.% at 90°C,
	NR	resistant to all conc. up to 40°C
	NBR	permeable to HCl
Ceramics and Glasses	Impervious graphite (Karbate®)	resistant to all conc. up to 165°C
	Borosilicated glasses (Pyrex®)	resistant to all conc. up to 190°C
	Fused silica and quartz	resistant to all conc. up to 200°C
	Silicon carbide (Carborundum®)	resistant to all conc. up to 190°C

Note: a material is satisfactory for handling hydrofluoric acid if the corrosion rate is maintained below 50 µm/y (i.e., 2 mpy).

Table F.5. Corrosion rates of materials in nitric acid (HNO_3)

Material class	Materials	Conc. and temp. range
Metals and Alloys	Carbon and low alloy steels	readily corroded
	Austenitic stainless steels (AISI 304, 316L): – use ELI carbon content (<0.05 wt.% C), – add carbide stabilizers (e.g., Ti, Nb), – soln. anneal. after welding, – addition of Si for HNO3 1005wt.	service up to 90°C with conc. below 30 wt.% service at RT with conc. until 100 wt.%
	Aluminum alloys series 30003 and 1001	for 93–100 wt.% until 30°C
	High-silicon cast iron (Duriron®, 14.4 wt.%Si)	resistant
	Titanium CP ASTM grade 2	resistant to all conc. up to b.p.
	Zircadyne® 702	resistant to conc. 65 to 90 wt.% up to b.p.

Table F.5. *(continued)*

Material class	Materials	Conc. and temp. range
Metals and Alloys	Hastelloy® C-276, Incoloy® 825, Chlorimet 3, 20Cb-3	resistant to all conc. up to b.p.
	Pure tantalum	resistant to all conc. up to b.p.
	Gold and Platinum	resistant to all conc. up to b.p. without chlorides
Ceramics and Glasses	Impervious graphite	resistant
	Borosilicated glasses	resistant to conc. up to 70 wt.% and until 125°C
	Carborundum®	resistant

Note: a material is satisfactory for handling nitric acid if the corrosion rate is maintained below 50 μm/y (i.e., 2 mpy).

Table F.6. Corrosion rates of materials in hydrofluoric acid and hydrogen fluoride (HF)

Corrosive	Material class	Materials	Conc. and temp. range
Hydrofluoric acid	Metals and Alloys	Pure copper	resistant to conc. below 70 wt.% from RT up to b.p.
		Red brass (Cu-15Zn)	resistant to conc. below 70 wt.% from RT up to b.p.
		Nickel grade 200 and Monel® 400	resistant to all conc. up to b.p.
		Magnesium metal	form a passivating film
		Gold and Platinum	resistant to all conc. up to b.p.
	Polymers and Elastomers	PE	
		PP	
		PVC	
		PVDC	
		PVDF	
		PTFE	
		NR	
		NBR	
	Ceramics and Glasses	Impervious graphite	resistant
		Sapphire	resistant
		Fluorite	

Note: a material is satisfactory for handling hydrofluoric acid if the corrosion rate is maintained below 50 μm/y (i.e., 2 mpy).

Table F.7. Corrosion rates of materials in sulfuric acid (H_2SO_4)

Corrosive	Material class	Materials	Conc. and temp. range
Sulfuric acid	Metals and Alloys	Carbon and low alloy steels, and gray cast iron	Only at room temperature for conc. ranging between 65 and 100 wt.% (other conc. require cathodic protection)
		Austenitic stainless steels AISI 304	above 93 wt.% up to 40°C
		Austenitic stainless steels AISI 316L	above 90 wt.% up to 40°C
		High-silicon cast iron (Duriron®, 14.4 wt.%Si)	all conc. from RT up to b.p.
		Zircadyne® 702	up to 50 wt.% up to b.p.
		Hastelloy® C-276	all conc. up to b.p.
		Incoloy® 825	below 40 wt.% and above 93 wt.%
		Monel® 400	up to 85 wt.% at 30°C (air free)
		Lead	up to 90%wt at RT
		Illium® B	up to 98 wt.% up to 100°C
		Pure tantalum	up to 98 wt.% up to b.p. (no free SO_3)
		Gold and Platinum	
	Polymers and Elastomers	PE	up to conc. 98 wt.% at RT
		PP	
		PVC	up to conc. 93 wt.% at RT
		PVDC	
		PVDF	up to conc. 98%wt and 65°C
		PTFE	all conc. up to 260°C
		NR	up to conc. 75 wt.% at RT
		NBR	
	Ceramics and Glasses	Silica brick and quarz	up to conc. 98 wt.% up to b.p.
		Borosilicated glasses	
		Carborundum®	

Note: a material is satisfactory for handling sulfuric acid if the corrosion rate is maintained below 50 μm/y (i.e., 2 mpy).

G Economic Data for Metals, Industrial Minerals and Electricity

G.1 Prices of Pure Elements

Table G.1. Prices of pure elements, metals and some alloys (2006)

Metal or alloy	Purity (wt.%)	Price (US$/tr.oz.)	Price (US$/lb.)	Price (US$/kg)
Aluminum	99.50	0.078	1.134	2.500
Aluminum powder	99.97	0.560–0.995	4.17–14.69	18–32
Aluminum powder	97.00	0.140–0.224	2.04–3.27	4.5–7.2
Antimony	99.99	6.843	99.8	220
Antimony	99.65	0.154	2.109	4.950
Arsenic	99.9	0.041	0.600	1.323
Barium	99.70	12.44	181.44	400.00
Beryllium	99.50	26.40	385.00	849.00
Beryllium-copper master	w/o	11.66	170	375
Bismuth	99.99	0.309	4.500	9.920
Boron	99.00	155.52	2267.96	5000
Cadmium	99.99	0.012	0.180	0.397
Cesium	99.99	630.87	9200	20,283
Calcium	99.90	0.151	2.20	4.85
Cerium	99.90	11.25	159	350
Chromium	99.00	0.213	3.107	6.850
Cobalt	99.80	1.008	14.70	32.41
Copper	99.9990	0.221	3.216	7.090
Dysprosium	99.90	17.11	249.50	550.00
Erbium	99.90	22.55	328.90	725.00
Europium	99.00	233.28	3401.94	7500.00

Table G.1. *(continued)*

Metal or alloy	Purity (wt.%)	Price (US$/tr.oz.)	Price (US$/lb.)	Price (US$/kg)
Ferro-chromium (*)	68–70 Cr	0.072	1.050	2.315
Ferro-manganese (*)	78 Mn	0.029	0.417	0.920
Ferro-molybdenum (*)	65–70 Mo	1.866	27.216	60.00
Ferro-niobium (*)	65–70 Nb	0.435	6.350	14.00
Ferro-silicon (*)	75 Si	0.037	0.544	1.200
Ferro-titanium (*)	70 Ti	0.560	8.164	18.00
Ferro-tungsten (*)	75W	0.964	14.061	31.00
Ferro-vanadium (*)	70–80 V	1.294	18.869	41.60
Gadolinium	99.00	15.09	219.99	485
Gallium	100.00	17.11	249.48	550
Germanium	99.99	52.88	771.00	1700
Gold 10 Kt	41.67	241	3524	7770
Gold 14 Kt	58.33	338	4929	10,867
Gold 18 Kt	75.00	435	6344	13,986
Gold 20 Kt	83.33	483	7044	15,529
Gold 24 Kt	99.995	580	8458.33	18,647
Hafnium	97.00	50.20	732.09	1614
Holmium	99.00	311.03	4535.92	10,000
Indium	99.97	31.103	453.59	1000
Iridium	99.999	400	5833	12,860
Iron	99.99	0.030	0.45	1.00
Iron (3 wt.% C)	97 wt.%	0.011	0.159	0.350
Lathanum	99.00	10.89	158.80	350
Lead	99.90	0.030	0.435	0.960
Lithium	99.80	2.97	43.27	95.40
Lutetium	99.00	233	3402	7500
Magnesium	99.80	0.056	0.816	1.840
Manganese	99.7	0.054	0.794	1.750
Mercury	99.99	0.288	4.211	9.282
Molybdenum (HIP)	99.95	4.06	59.26	130.65
Molybdenum (VAR)	99.9	6.857	100	220.46
Neodymium	99.00	14.0	204.0	450
Nickel	99.00	0.700	10.206	22.50
Niobium	99.90	6.88	100.40	221.34
Niobium-1 wt.% Zr	99.00	7.95	116.00	255.74
Osmium	99.999	450	6563	14,468
Palladium	99.999	336	4900	10,803
Platinum	99.999	933	13,606.25	29,997
Potassium	99.90	2.80	40.82	90.00
Praseodymium	99.00	16.80	245	540
Rhenium	99.90	27.99	408.23	900

Table G.1. *(continued)*

Metal or alloy	Purity (wt.%)	Price (US$/tr.oz.)	Price (US$/lb.)	Price (US$/kg)
Rhodium	99.9	4850	70,729	15,6931
Rubidium	99.80	2479	36,151	79,700
Ruthenium	99.999	180	2625	5787
Samarium	99.99	9.33	136	300
Selenium	99.50	1.440	21	46.29
Silicon (EG)	99.5–99.9	34.213	498.95	1100
Silicon (MG)	98–98.5	0.06	0.88	1.94
Silicon (SG)	99.99	97.198	1417.48	3125
Silver	99.99	10.45	152	336
Sodium	99.90	2.05	29.94	66.00
Stainless steel 304	w/o	0.106	1.542	3.400
Strontium	99.95	311	4536	10,000
Tantalum	99.90	17.03	248.3	550
Tantalum-2.5 W	w/o	20.839	304	670
Tellurium	99.50	1.51	22.00	48.50
Terbium	99.00	933.10	13,607.77	30,000
Terbium	99.90	1555.17	22,679.62	50,000
Thallium	99.00	39.8	580	1279
Thorium	99.90	150.00	2187.57	4822.76
Tin	99.90	0.246	3.583	7.900
Titanium (high purity)	99.99	3.51	51.26	113.00
Titanium alloy Ti-0.25Pd	–	7.63	111.29	245.35
Titanium alloy Ti-6Al-4V	–	1.53	22.36	49.24
Titanium ASTM Grade 2	99.80	1.714	25.00	55.10
Titanium scrap	n.a.	0.124	1.810	4.00
Titanium sponge	98.5	0.295	4.309	9.50
Tungsten	99.90	22.95	335	750
Uranium	99.00	0.542	7.90	17.42
Vanadium	99.00	50.00	729.17	1607.54
Ytterbium	99.90	49.8	725.7	1600
Yttrium	99.90	14	204	450
Zinc	99.995	0.096	1.393	3.070
Zircadyne® 702	99.00	3.42	50	110
Zirconium	99.80	7.15	104	230

Notes: (*) prices of ferroalloys are reported per unit mass of metal contained.
References: Mining Journal, Metal Bulletin Weekly, Mineral PriceWatch, Roskill Information Services, US Geological Survey, and Industrial Minerals

G.2 World Annual Production of Commodities

Table G.2. Commodities world annual production in decreasing order (2005)

Element	World annual production (/tonnes)
Crude oil	202,000,000,000
Natural gas	186,000,000,000
Cement	20,000,000,000
Coal	5,000,000,000
Iron and steel	1,040,000,000
Rock salt	225,000,000
Aluminum	21,720,000
Copper	11,394,000
Zinc	8,900,000
Lead	5,994,000
TiO_2 feedstocks	5,900,000
Nickel	1,033,000
Stainless steels	1,000,000
Magnesium	480,000
Titanium	170,000
Tin	150,000
Molybdenum	135,624
Sodium	108,000
Vanadium	46,000
Tungsten	42,050
Uranium	36,112
Mercury	33,929
Silver	15,769
Cadmium	19,263
Cobalt	9328
Gold	2604
Tantalum	2267
Bismuth	2030
Zirconium	1000
Lithium	1000
Palladium	254
Beryllium	230
Indium	189
Platinum	178

G.3 Economic Data for Industrial Minerals

Table G.3. Economic data for industrial minerals (2005)

Industrial mineral or rock	Major producing countries (annual production) (/10^3 tonnes)	World annual production (/tonnes)	Grade and price range (US$/tonne)
Alumina (non metallurgical grade)	Australia (44,100), USA (5100), and Jamaica (3400)	50,000,000	calcined alumina (CA): 75–85 tabular alumina (TA): 435–580 white fused alumina (WFA): 600–900 brown fused alumina (BFA): 600–700
Andalusite	South Africa (190), France (80), USA, and China	240,000	Andalusite (57–58 wt.% Al_2O_3): 200–250
Antimony oxide	China		Lump ore (60 wt.% Sb): 8–9 99.5 wt.% Sb_2O_3: 1750–2800
Asbestos (i.e., chrysotile, crocidolite, amosite, anthophyllite, tremolite, and actinolite)	Russia (700), Canada (335), China (250) Brazil (170), Zimbabwe (130), Kazakhstan (125), Greece (35), Swaziland (25), Republic of South Africa (20)	1,800,000	Chrysotile: 150–1200 Crocidolite: 650–920
Apatite (see also phosphate rock)	USA (42,000), Morocco (25,000), and China (20,000)	70,000,000	Bone phosphate of lime: 45–50
Attapulgite and sepiolite (i.e., palygorskite or Fuller's earth)	USA (725), Senegal (103), Spain (94), Australia (19), and South Africa (9)	950,000	Attapulgite: 110
Ball clay	China, USA		35–190
Baryte (heavyspar)	China (3800), India (650), USA (600), Morocco (320), Turkey (200)	6,000,000	Lump ore: 42–52 Ground ore: 68–85 350 mesh, 96–98 wt.%: 200–320
Bauxite (i.e., gibbsite, boehmite, and diaspore)	China (4000), Greece (700), Brazil (350), France (300), Guyana (120)	122,000,000	Refractory grade: 140–160 Abrasive grade: 100–120
Bentonite (Montmorillonite clay)	USA (4100), Greece (1020), CIS (918), India (816), Turkey, and Italy	10,200,000	Foundry grade: 55–60 Litter grade: 40–65 API grade: 140–150 Civil engng. grade: 50–60
Beryl and bertrandite	USA (2500), Russia (1000), Kazakhstan (100)	3630	Beryl ore (10 wt.% BeO): 75–90

Table G.3. *(continued)*

Industrial mineral or rock	Major producing countries (annual production) (/10^3 tonnes)	World annual production (/tonnes)	Grade and price range (US$/tonne)
Borax and borates (kernite, tincal, colemanite, and ulexite)	Turkey (1400), USA (1070), Russia (1000), Argentina (350), Chile (200), and China (105)	4,220,000	Colemanite (40–42% B_2O_3): 270–290 Ulexite (40% B_2O_3): 250–300 Borax $10H_2O$: 350–390 Borax $5H_2O$: 400–450 Borax anhydrous: 900–950
Brucite	China, and USA	20,000	
Chromite (i.e., stratiform, podiform)	Republic of South Africa (6970), India (1401), Turkey (818), Zimbabwe (701), Finland (584), Brazil (467), and Iran (234)	11,679,000	Chemical grade: 150–165 Foundry grade: 195–225 Refractory grade: 210–240
Celestite	China, Germany, Mexico, Spain	420,000	Celestite (94 wt.%$SrSO_4$): 60–100
Diatomite (Kiesielguhr)	USA, Spain, Denmark, and France	2,000,000	Diatomite filter-aids: 850–930
Emery (corundum, magnetite, and spinel)	Turkey (24), Greece (10), and USA (3)	37,000	Coarse grain emery: 296–388 Medium grain emery: 374 Fine grained emery: 416
Feldspars (orthoclases and plagioclases)	Italy (2600), Turkey (1100), USA (875), France (600), Thailand (500), Germany (460), Spain (425)	9,000,000	Ceramic grade (325 mesh): 115–130 Glass grade low Fe (30 mesh): 22 Glass grade high Fe (30 mesh): 19
Fluorspar	China (2200), Mexico (700), Russia, South Africa, Mongolia, Spain, France	5,000,000	HF acid grade: 200–240 Metallurgical grade: 130–160
Fused silica (high purity silica sand 99.9 wt.% SiO_2 melted in a carbon electrode arc furnace)	USA (100), China, Singapore, South Korea, and Japan	200,000	High-purity grade (99.9 wt.%): 285–360 Lower-purity grade (99.5 wt.%): 260–340
Garnet (pyrope, almamdine, spessartine, uvarovite, grossular, andradite)	USA (101), India (100), Australia (100), and China	335,000	Almandine (8–250 mesh): 170–240
Graphite (crystalline, flake, microcrystalline, amorphous)	China (220), India (145), Brazil (61), Mexico (44), Ukraine (40), Czech Republic (30), Canada (25).	480,000	Crystalline flakes (90–94 wt.% C): 270–750 Amorphous powder (80–85 wt.% C): 220–235 Synthetic powder (99.95 wt.%): 1970

Table G.3. *(continued)*

Industrial mineral or rock	Major producing countries (annual production) (/10^3 tonnes)	World annual production (/tonnes)	Grade and price range (US$/tonne)
Gypsum and anhydrite	USA (19,400), Thailand (9000), Iran (9000), China (9200), Canada (8200), Spain (7400), Mexico (7100), and Japan (5300)	110,000,000	Crude gypsum: 7 Calcined gypsum: 17
Ilmenite and leucoxene	Canada, Australia, Norway, South Africa	3,000,000	Ilmenite (54 wt.% TiO_2): 85–95 Leucoxene (91 wt.% TiO_2): 350–500
Iron oxides (hematite, magnetite)	India (500), USA (70) and Spain (8)	1,100,000	Hematite (79.wt.% Fe_2O_3):
Iodine	Chile (11), Japan (7), USA (2)	20,000	Iodine crystal: 13,000–14,500
Kaolin (China clay)	USA (8870), Brazil (1700), UK (2300), Czech Republic (6000), Iran (900), Germany (700), and South Korea (670)	39,000,000	filler grade: 80–100 Calcined grade: 330–395 Sanitary grade: 65–75
Kyanite	USA (90), Australia (1), Brazil, China (3), India (5) and Zimbabwe (4)	110,000	Calcined (54–60 wt.% Al_2O_3): 280–350 Raw (54–60 wt.% Al_2O_3): 180–240
Magnesite	China, Russia, Slovakia, Turkey, and Spain	19,000,000	Caustic magnesia: 200 Dead burned magnesia: 400 Electrofused magnesia: 600
Manganese dioxide and rhodocrosite	Africa (167), Europe (58), Australia (35), South America (8), North America (3)	271,000	Electrolytic (EMD): 1750–1800 Chemical (CMD):1400–1600 Natural (NMD): 950–1000
Mica (muscovite ground)	USA, and CIS	305,200	Dry-ground: 230–400 Wet-ground: 535–1400
Mica (muscovite sheet)	India (4), China, Argentina, Brazil, South Africa, and Madagascar	5000	Low-quality: 200–430 Highest-quality: 600–1200
Mullite (synthetic)	Germany, Italy, Japan, USA, and the UK	60,000	Fused mullite: 1000–1500 Fused zirconia mullite: 1200–1500 Sintered mullite: 750–1350
Nepheline syenite	Canada, Norway, USA	900,000	Norway: 165–210 Canada: 57–60

Table G.3. *(continued)*

Industrial mineral or rock	Major producing countries (annual production) (/10^3 tonnes)	World annual production (/tonnes)	Grade and price range (US$/tonne)
Nitrates (soda niter and salpeter)	Chile (980), Israel (520), USA (180), Denmark (70), Norway (30), Russia (22), Poland (10), Ukraine (5)	1,817,000	Soda niter ($NaNO_3$): 215 Salpeter (KNO_3):
Olivine (fayalite and forsterite, synthetic by calcining chrysotile asbestos mining tailing)	Norway (3500), USA, Japan, South Korea, Taiwan, Spain, Italy, Brazil, Mexico	4,000,000	Concentrate: 15–20 Refractory grade: 85–95 Foundry grade: 90–140 Turndish spray: 115–150 EBT taphole filler: 85–95
Perlite	USA (650), Greece (500), Hungary (250), Japan (250), Turkey (150)	2,000,000	Expanded perlite: 210–410 Graded perlite: 30–60 Raw perlite: 15–20
Petalite	Australia (100), Canada, Zimbawe	200,000	Petalite (4.2 wt.% Li_2O): 165–260
Phosphate rock (i.e., apatite, fluoroapatite, hydroxyfluoroapatite)	USA (41,500), Morocco (24,000), China (20,000), Russia (11,000), Tunisia (8000), Jordan (5346), and Israel (4016)	133,871,000	Phosphate rock (65–72% bpl): 32–46 Monoammonium phosphate (MAP): 180 Diammonium phosphate (DAP): 145 Triple superphosphate (TSP): 120
Potash	Canada (9), Russia (4.5), Germany (3.5), Belarus (3.5), Israel (1.8), Jordan (1.2)	28,000	Muriate of potash (60 wt.% K_2O): 140–145
Pumice and pozzolan	Italy (5600), Greece (900), Turkey (812), USA (580), Germany (580), Spain (580), France (464), Chile (464)	11,600,000	Abrasive: 164 Stone washing: 121 Landscaping: 29 Concrete block: 15
Pyrite	China (3.5), Finland (0.5), Russia, South Africa, Spain, Japan	4500	
Pyrophyllite (Rozeckite)	South Korea (900), Japan (30), China (20)	923,000	Pyrophyllite ore: 10 Processed pyrophyllite: 150–400
Quartz crystals (i.e., lascas)	Brazil (1.594), CIS, USA, Madagascar, Namibia, Angola, South Africa, Venezulela	2168	780

Table G.3. *(continued)*

Industrial mineral or rock	Major producing countries (annual production) (/10^3 tonnes)	World annual production (/tonnes)	Grade and price range (US$/tonne)
Rutile (natural and synthetic)	South Africa, Australia, Sierra Leone	1,000,000	Natural (91–95 wt.% TiO_2): 480 Synthetic (95 wt.% TiO_2): 410
Salt (Halite, rock salt)	USA (45,000), China (32,000), Germany (16,000), India (15,000), Canada (12,000)	225,000,000	Rock salt: 40–60 Solar salt: 15–30
Silicon carbide (Carborundum)	Norway, USA, Netherlands, Ukraine, Brazil, Japan	400,000	Black grade (99%): 1300–1500 Refractory grade (98 wt.%): 1800–2200 Refractory grade (95 wt.%): 1600–1900
Soda ash (see also trona and macholite)	USA (15,700), Kenya (220)	16,000,000	Soda ash: 85–150
Spinel	USA (25), Brazil, and Japan	30,000	
Spodumene and lepidolite	Australia, Canada	100,000	Concentrate (7.25 wt.% Li_2O): 460–490 Glass grade (7.25 wt.% Li_2O): 270–310
Sulfur	USA, Canada, China, and Russia	57,600,000	Canadian liquid bright: 60–70 Canadian solid state: 24–31
Talc	USA (850), India (450), France (350), Finland (400), Brazil (300)	5,300,000	Plastic grade: 200–210 Ceramic grade: 100 Micronized: 450–590
Titanium slag (sulfate and chloride)	Canada (1000), South Africa (1000), Norway (150)	2,150,000	80 wt.% TiO_2: 338 85 wt.% TiO_2: 385 95 wt.% TiO_2: 520
Trona and nacholite (sodium carbonate and bicarbonate)	USA (15,700), Kenya (220)	16,000,000	Soda ash: 85–150
Vanadium pentaoxide	South Africa, Australia, USA		98 wt.% V_2O_5: 3000–5000
Vermiculite	China, USA		Raw: 160–260
Wollastonite	China (320), USA (150), Mexico, India	640,000	Acicular grade: 205–300
Zeolites	China (2500), Cuba (600), Japan (160), USA (43), Hungary (20), Slovakia (12), Georgia (6).	3500	
Zircon sand	Australia (520), South Africa (395), and USA (145)	1,280,000	66–67 wt.% ZrO_2: 1000

References: USGS Mineral Yearbook, Roskill Information Services Ltd., Industrial Minerals Information Ltd., Minerals PriceWatch, Mining Journal, Mineral Sands Report, and Metal Bulletin Weekly.

G.4 Prices of Electricity in Various Countries

Table G.4. Prices of electricity for selected countries (2004)

Country	Electricity[1] (US$/kWh)
Australia	0.056
Brazil	0.083
Canada	0.030
India	0.059
Japan	0.128
Norway	0.052
Russia	0.432
South Africa	0.021
United States	0.043

[1] UK Electricity Association; prices include local taxes but exclude recoverable VA

H Geological Time Scale

See Figure H.1, page 1256.

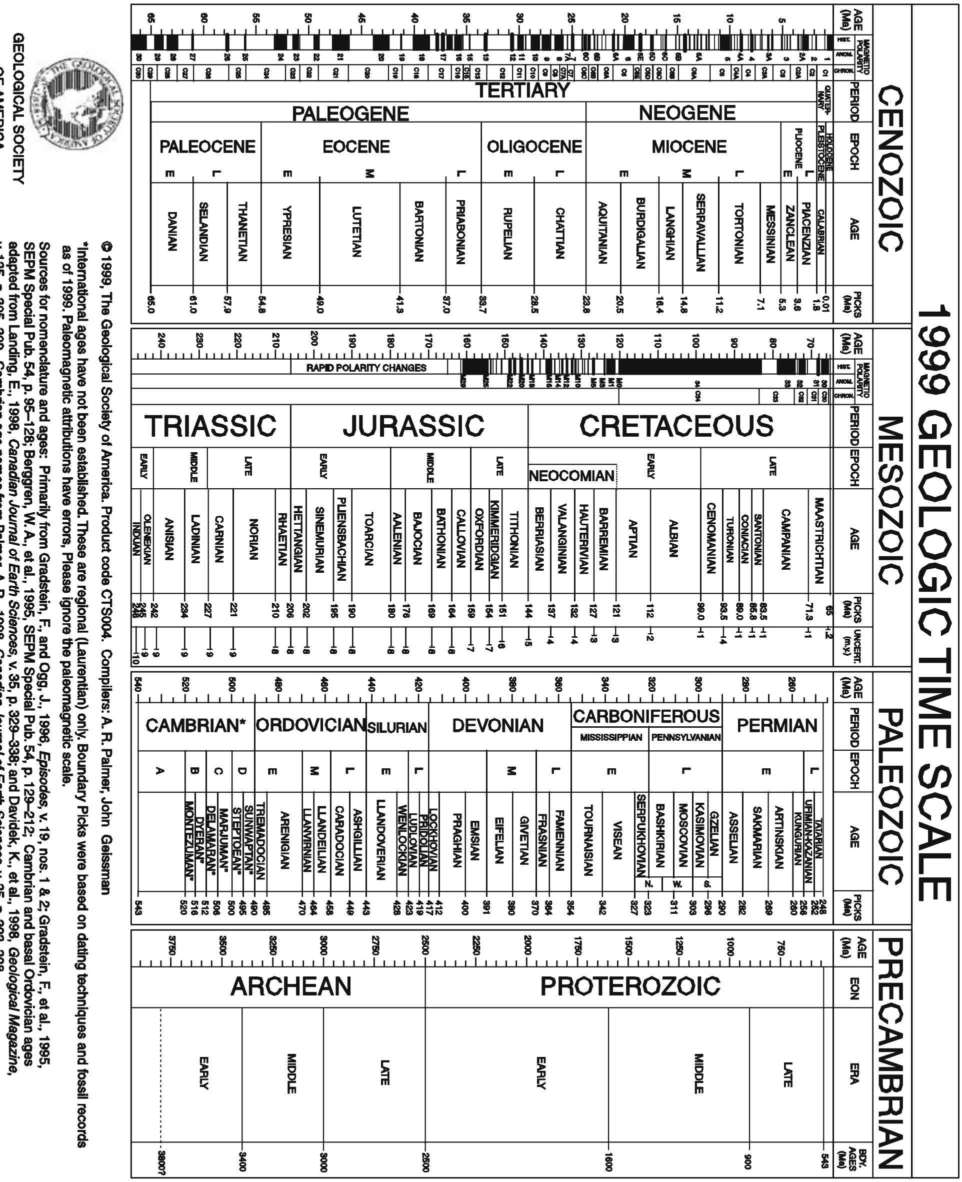

Figure H.1. Geological Time Scale. Copyright © 1999 by the Geological Society of America (GSA). Reproduced by permission of the Geological Society of America.

I Materials Societies

Table I.1. Materials related professional societies

Acronym	Professional Society	Address
AA	Aluminum Association Inc. (AA)	1525 Wilson Boulevard, Suite 600, Arlington, VA 22209, United States Telephone: (703) 358-2960 Fax: (703) 358-2961 Internet: http://www.aluminum.org/
ACarS	American Carbon Society (ACarS)	Internet: http://www.americancarbonsociety.org/
ACerS	American Ceramic Society (ACerS)	735 Ceramic Place, Suite 100, Westerville, Ohio 43081 Telephone: (866) 721-3322 Fax: (614) 899-6109 E-mail: info@ceramics.org Internet: http://www.ceramics.org/
ACS	American Chemical Society (ACS)	1155 16th Street, N.W., Washington, DC 20036, United States Telephone: (202) 872-4600 Internet: http://www.chemistry.org/
ACMA	American Composite Manufacturers Association (ACMA)	1010 North Glebe Road, Suite 450 Arlington VA, United States Telephone: (703) 525-0511 Fax: (703) 525-0743 E-mail: info@acmanet.org Internet: http://www.acmanet.org/
ACI	American Concrete Institute (ACI)	P.O. Box 19150, Detroit, MI 48219, United States Telephone: (313) 930-9277 Fax: (313) 930-9088 E-mail: service@cssinfo.com Internet: http://www.cssinfo/info/aci.html
ACA	American Crystallographics Association (ACA)	P.O. Box 96, Ellicott station, Buffalo NY 14205-0096, United States Internet: http://www.hwi.buffalo.edu/ACA/

Table I.1. *(continued)*

Acronym	Professional Society	Address
ADA	American Dental Association (ADA)	211E. Chicago Avenue, Chicago, IL 60611, United States Telephone: (312) 440-2500 Fax: (312) 440-2800 Internet: http://www.ada.org/
AESF	American Electroplaters and Surface Finishers Society (AESF)	12644 Research Parkway, Orlando FL 32826-3298, United States Telephone: (407) 281-6441 Fax: (407) 281-6446 Internet: http://www.aesf.org/
AGA	American Gas Association (AGA)	400 N Capitol Street, Washington DC 20001, United States Telephone: (202) 824-7000 Fax: (202) 824-7115 Internet: http://www.aga.org/
AGU	American Geophysical Union (AGU)	2000 Florida Avenue N.W., Washington, DC 20009-1277, United States Telephone: (202) 462-6900 Fax: (202) 328-0566 E-mail: service@kosmos.agu.org Internet: http://www.agu.org/
AIAA	American Institute of Aeronautics and Astronautics (AIAA)	Suite 500, 1801 Alexander Bell Drive, Reston, VA 20191-4344 United States Telephone: (703) 264-75 00 Fax: (703) 264-75 51 Internet: http://www.aiaa.org/
AIChE	American Institute of Chemical Engineers (AIChE)	Three Park Avenue, New York, New York, 10016-5901, United States Telephone: (212) 591-7338 Internet: http://www.aiche.org/
AIE	American Institute of Engineers (AIE)	1018 Appian Way, El Sobrante, CA 94803-3142, United States Telephone: (510) 223-8911 Fax: (888) 868-9243 E-mail: aie@members-aie.org Internet: http://www.members-aie.org/
AIGS	Asian Institute of Gemmological Sciences (AIGS)	919/1 Jewelry Trade Center, North Tower 33rd Floor, Silom Road, Bangrak Bangkok 10500, Thailand Telephone: (66-2) 267-4315-9 Fax: (66-2) 267-4320 E-mail: info@aigsthailand.com Internet: http://www.aigsthailand.com/contactlist.php
AIME	American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME)	Three Park Avenue, New York, New York, 10016, United States Telephone: (212) 419-7676 Fax: (212) 419-7671 Internet: http://www.aimeny.org/
AIP	American Institute of Physics (AIP)	One Physics Ellipse, College Park, MD 20740-3843, United States Telephone: (301) 209-3100 Fax: (301) 209-0843 Internet: http://www.aip.org/

Table I.1. *(continued)*

Acronym	Professional Society	Address
AISI	American Iron and Steel Institute (AISI)	1101, 17th Street NW, Washington D.C., 20036, United States Telephone: (202) 452-7100 Internet: http://www.steel.org/
ANS	American Nuclear Society (ANS)	555 North Kennington Avenue, La Grange Park, IL 60526, United States Telephone: (708) 352-6611 Fax: (708) 579-0499 E-mail: nucleus@ans.org Internet: http://www.ans.org/
API	American Petroleum Institute (API)	1220 L Street NW, Washington D.C., 20005, United States Telephone: (202) 682-8000 Internet: http://www.api.org/
APS	American Physical Society (APS)	One Physics Ellipse, College Park, MD 20740-3844, United States Telephone: (301) 209-3200 Fax: (301) 209-0865 E-mail: opa@aps.org Internet: http://www.aps.org/
ASM	American Society for Metals (ASM)	9639 Kinsman Road, Materials Park, OH 44073-0002, United States Telephone: (440) 338-5151 Fax: (440) 338-4634 Internet: http://www.asm-intl.org/
ASNDT	American Society for Nondestructive Testing (ASNDT)	P.O. Box 28518 1711 Arlingate Lane Columbus, OH 43228-0518 United States Internet: http://www.asnt.org/
ASTM	American Society for Testing and Materials (ASTM)	100 Barr Harbor Drive W. Conshohocken PA 19428-2959 United States Telephone: (202) 862-5100 Internet: http://www.astm.org/
ASCE	American Society of Civil Engineers (ASCE)	1015 15th Street Suite 600 Washington DC 20005 United States Telephone: (202) 789 2200 Fax: (202) 289 6797 Internet: http://www.asce.org/
ASME	American Society of Mechanical Engineers (ASME)	3 Park Avenue, New York, New York, 10016-5990, United States Telephone: (212) 705-7722 Internet: http://www.asme.org/
ASNE	American Society of Naval Engineers (ASNE)	1452 Duke Street Alexandria, Virginia, 22314-3458 Telephone: (703) 836-6727 Fax: (703) 836-7491 Internet: http://www.navalengineers.org/
AVS	American Vacuum Society (AVS)	120 Wall Street-32 floor, New York, NY 10005, United States Telephone: (212) 248-0200 Fax: (212) 248-0245 Internet: http://www.vacuum.org/

Table I.1. *(continued)*

Acronym	Professional Society	Address
AWS	American Welding Society (AWS)	550, NW LeJeune Road, P.O. Box 351040, Miami, Florida, FL-33126, United States Telephone: (305) 443-9353 Fax: (305) 443-7559 Internet: http://www.amweld.org/
AZA	American Zinc Association (AZA)	2025 M Street NW Suite 800 Washington DC 20036, United States Telephone: (202) 367-1151 Fax: (202) 367-2232 Internet: http://www.zinc.org/
AIST	Association for Iron and Steel Technology (AIST)	186 Thorn Hill Road Warrendale, PA 15086, United States Telephone: 724-776-6040 Fax: 724-776-1880 E-mail: info@aist.org Internet: http://www.aist.org/
ATITAN	Association Titane (ATITAN)	Centre des Salorges, 16, quai E. Renaud, BP 90517, F-44105 Nantes Cedex 4, France Telephone :+33(0)2 40 44 60 57 Fax :+33(0)2 40 44 63 80 E-mail: m.brau@nantes.cci.fr Internet: http://www.titane.asso.fr/
AIM	Associazione Italiana di Metallurgia (AIM)	Piazza R. Morandi, 2 - 20121 Milamo, Italy Telephone: (+39) 02.76021132 Fax: (+39) 02.76020551 E-mail: aim@aimnet.it Internet: http://www.metallurgia-italiana.net/
ACPS	Australian Coal Preparation Society (ACPS)	P.O. Box 208, The Junction NSW 2291, Australia Telephone: (02) 49264870 Fax: (02) 49264902 E-mail: acpsnsw@acps.com.au Internet: http://www.acps.com.au/
AuGS	Australian Geological Survey (AuGS)	GPO Box 378, Canberra ACT 2601, Australia Telephone: (+61) 2 6249 9111 Fax: (+61) 2 6249 9999 Internet: http://www.ga.gov.au/
BEME	Benelux Metallurgie (BEME)	CP 165/71, Université Libre de Bruxelles, Avenue F.D. Roosevelt, 50, B-1050 Bruxelles, Belgium Telephone: (+32)-2-650.30.10 / 29.93 Fax: (+32)-2-650.36.53 Internet: http://www.beneluxmetallurgie.be/
ABM	Brazilian Association for Materials and Metallurgy (ABM)	R. Antonio Comparato, 218, Campo Belo, São Paulo - SP, CEP 04605-030, Brazil Telephone: (11) 5536-4333 Fax: (11) 5044-4273 E-mail: abm@abmbrasil.com.br Internet: http://www.abmbrasil.com.br/

Table I.1. *(continued)*

Acronym	Professional Society	Address
BGS	British Geological Survey (BGS)	Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG, united Kingdom Telephone: +44 (0)115 936 3100 Fax: +44 (0)115 936 3200 Internet: http://www.bgs.ac.uk/
BRGM	Bureau de Recherches Géologiques et Minières (BRGM)	3 avenue Claude-Guillemin, BP 36009 F-45060 Orléans Cedex 2, France Telephone: +33(0)2 38 64 34 34 Internet: http://www.brgm.fr/
CCDC	Cambridge Crystallographic Data Centre (CCDC)	12 Union Road Cambridge CB2 1EZ, United Kingdom Telephone:+44 1223 336408 Fax:+44 1223 336033 E-mail: admin@ccdc.cam.ac.uk Internet: http://www.ccdc.cam.ac.uk/
CAFA	Canadian Foundry Association (CAFA)	1 Nicholas Street, Suite 1500, Ottawa, Ontario K1N 7B7, Canada Telephone: (613) 789-4894 Fax: (613) 789-5957 Internet: http://www.foundryassociation.ca/
CGA	Canadian Gemmological Association (CGA)	1767 Avenue Road, Toronto, Ontario M5M 3Y8 Canada Telephone: (416) 785-0962 Fax: (416) 785-9043 E-mail: info@canadiangemmological.com Internet: http://www.canadiangemmological.com/
CIM	Canadian Institute of Mining, Metallurgy and Petroleum.	Suite 855, 3400 de Maisonneuve Blvd. W., Montreal, QC H3Z 3B8, Canada Telephone: (514) 939-2710 Fax: (514) 939-2714 E-mail: cim@cim.org Internet: http://www.cim.org/
CerSJ	Ceramic Society of Japan (CerSJ)	2-22-17 Hyakunincho, Shinjuku, Tokyo 169-0073, Japan Fax: +81-3-3362-5714 E-mail: information@cersj.org Internet: http://www.ceramic.or.jp/i
CDI	Cobalt Development Institute (CDI)	167 High Street, Guildford, Surrey, GU1 3AJ, United Kingdom Telephone: +44 1483 578877 Fax: +44 1483 573873 Internet: http://www.thecdi.com/
CDA	Copper Development Association (CDA)	260 Madison Avenue, New York, NY 10016, United States Telephone: (212) 251-7200 Fax: (212) 251-7234 E-mail: questions@cda.copper.org Internet: http://www.cda.org/

Table I.1. *(continued)*

Acronym	Professional Society	Address
DIS	Ductile Iron Society (DIS)	28938 Lorain Road, Suite 202; North Olmsted, OH 44070, United States Telephone: (440) 734-8040 Fax (440) 734-8182 E-mail: jhall@ductile.org Internet: http://www.ductile.org/
EPRI	Electric Power Research Institute (EPRI)	3412 Hillview Avenue, Palo Alto, CA 94304-1395, United States Telephone: (650) 855-2000 Internet: http://www.epri.com/
ECS	Electrochemical Society (ECS)	10 South Main Street, Pennington NJ 08534-2896, United States Telephone: (609) 737-1902 Fax: (609) 737-2743 E-mail: ecs@electrochem.org Internet: http://www.electrochem.org/
Euro-Chlor	EuroChlor	Avenue E Van Nieuwenhuyse 4, box 2, B-1160 Brussels, Belgium Telephone: + 32 2 676 7211 Fax: + 32 2 676 7241 E-mail: eurochlor@cefic.be Internet: http://www.eurochlor.org/
ECerS	European Ceramic Society (ECerS)	Ave. Gouverneur Cornez , 4, B-7000 Mons, Belgium Telephone: (+32) (0)65 403421 Fax: (+32) (0)65 403458 E-mail: ecers@bcrc.be Internet: http://www.ecers.org/
EPMS	European Powder Metallurgy Society (EPMS)	2nd Floor Talbot House Market Street, Shrewsbury, SY1 1LG United Kingdom Telephone: +44 (0)1743 248899 Fax: +44 (0)1743 362968 E-mail: info@epma.com Internet: http://www.epma.com/
GAA	Gemmological Association of Australia (GAA)	Internet: http://www.gem.org.au/
GAGB	Gemmological Association of Great Britain (GAGB)	Telephone: (+44) 020 74043334 Fax: (+44) 020 7404 8843 E-mail: information@gem-a.info Internet: http://www.gagtl.ac.uk/
GIA	Gemological Institute of America (GIA)	World Headquarters and Robert Mouawad Campus 5345 Armada Drive, Carlsbad, CA 92008, United states Telephone: (760) 603-4000 Internet: http://www.gia.edu/
GSA	Geological Society of America (GSA)	3300 Penrose Place, Boulder, CO 80301, United States Telephone: (303) 447-2020 Fax: (303) 447-1133 E-mail: web@geosociety.org Internet: http://www.geosociety.org/

Table I.1. *(continued)*

Acronym	Professional Society	Address
GSC	Geological Survey of Canada (GSC)	601 Booth Street, Ottawa, Ontario, K1A 0E8, Canada Telephone: (613) 996-3919 Fax: (613) 943-8742 E-mail: info-ottawa@gsc.nrcan.gc.ca Internet: http://gsc.nrcan.gc.ca/
GCA	German Gemmological Association (GGA)	Prof.-Schlossmacher-Str. 1, D-55743 Idar-Oberstein, Germany Telephone: (+49)-6781-43011 Fax: (+49)-6781-41616 Internet: http://www.gemcertificate.com/
GI	Gold Institute (GI)	1112 16th Street, N.W., Suite 240, Washington D.C. 20036, United States Telephone: (202) 835 0185 Fax: (202) 835 0155 E-mail: info@goldinstitute.org Internet: http://www.responsiblegold.org/
IMA	Industrial Minerals Association (IMA)	Bd. S. Dupuis, 233 Box 124, B-1070 Brussels, Belgium Telephone: 32 2 524 55 00 Fax: 32 2 524 45 75 E-mail: secretariat@ima-eu.org Internet: http://www.ima-eu.org/
IEEE	Institute of Electrical and Electronics Engineers (IEEE)	445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-0459, United States Telephone: (732) 981 0060 Fax: (732) 981 0225 Internet: http://www.ieee.org/
IOM	Institute of Materials (IOM3)	1 Carlton House Terrace, London, SW1Y 5DB, United Kingdom Telephone: +44 (0)20 7451 7300 Fax: +44 (0)20 7839 1702 Internet: http://www.iom3.org/
ICA	International Cadmium Association (ICA)	168 Avenue Tervueren /Box 4, B-1150 Brussels, Belgium Teephonel: +32(0)2 777.05.60 Fax: +32 (0)2 777.05.65 E-mail: info@cadmium.org Internet: http://www.cadmium.org/
ICDA	International Chromium Development Association (ICDA)	45 rue de Lisbonne, F-75008 Paris, France Telephone: (+33) 1 40 76 06 89 Fax: (+33) 1 40 76 06 87 E-mail: info@icdachromium.com Internet: http://www.icdachromium.com/
IISI	International Iron and Steel Institute (IISI)	Rue Colonel Bourg 120, B-1140 Brussels Belgium Telephone:+32 2 702 89 00 Fax:+32 2 702 88 99 E-mail: info@iisi.be Internet: http://www.worldsteel.org/

Table I.1. *(continued)*

Acronym	Professional Society	Address
ILZRO	International Lead-Zinc Research organization Inc. (ILZRO)	2525 Meridian Parkway, P.O. Box 12036 - Research Triangle Park, NC 27709-2036, United States Telephone: (919) 3614647 Fax: (919) 361-1957 E-mail: rputnam@ilzro.org Internet: http://www.ilzro.org/
IMA	International Magnesium Association (IMA)	1303 Vincent Place, Suite One, McLean, VA 22101 United States Telephone: (703) 442-888 Fax: (703) 821-1824 E-mail: ima@bellatlantic.net Internet: http://www.intlmag.org/
IMI	International Manganese Institute (IMI)	17 avenue Hoche, F-75008 Paris, France Telephone: +33 (0) 1 45 63 06 34 Fax: +33 (0) 1 42 89 42 92 E-mail: info@manganese.org Internet: http://www.manganese.org/
IMA	International Mineralogical Association (IMA)	15, rue Notre Dame des Pauvres B.P. 20, F-54501 Vandoeuvre-les-Nancy Cedex, France Telephone: +33 (0)3 83 59 42 46 Fax: +33 (0)3 83 51 17 98 E-mail: mohnen@crpg.cnrs-nancy.fr Internet: http://www.ima-mineralogy.org/
IMOA	International Molybdenum Association (IMOA)	Unit 7 Hackford Walk, 119-123 Hackford Road, London SW9 0QT, United Kingdom Telephone: +44 171 582 2777 Fax: +44 171 582 0556 Internet: http://www.imoa.org.uk
IPI	International Potash Institute (IPI)	Baumgärtlistrasse 17, P.O. Box 569, CH-8810 Horgen, Switzerland Telephone: + 41 43 810 49 22 Fax: + 41 43 810 49 25 E-mail: ipi@ipipotash.org Internet: http://www.ipipotash.org/
IPMI	International Precious Metals Institute (IPMI)	4400 Bayou Blvd., Suite 18 Pensacola, FL 32503-1908, United States Telephone: (850)476-1156 Fax: (850) 476-1548 E-mail: ipmi@pond.com Internet: http://www.ipmi.org/
ITRI	International Tin Research Institute Ltd. (ITRI)	Unit 3, Curo Park Frogmore St. Albans Hertfordshire AL2 2DD, United Kingdom Telephone: +44 (0) 1727 875 544 Fax: +44 (0) 1727 871 341 E-mail: info@itri.co.uk Internet: http://www.itri.co.uk/

Table I.1. *(continued)*

Acronym	Professional Society	Address
ITA	International Titanium Association (ITA)	1871 Folsom Street, Suite 200 Boulder, CO 80302-5714, United States Telephone: (303) 443-7515 Fax: (303) 443-4406 E-mail: afitz@titanium.net Internet: http://www.titanium.org/
ITIA	International Tungsten Industry Association (ITIA)	Unit 7 Hackford Walk, 119-123 Hackford Road, London SW9 0QT, United Kingdom Telephone: +44 171 582 2777 Fax: +44 171 582 0556 E-mail: info@itia.info Internet: http://www.itia.org.uk
IZA	International Zinc Association (IZA)	168 Avenue de Tervueren Box 4, B-1150 Brussels, Belgium Telephone: + 32 2 776 00 70 Fax: + 32 2 776 00 89 E-mail: info@iza.com Internet: http://www.iza.com/
IMAM	Iron Mining Association of Minnesota (IMAM)	11 East Superior Street, Suite 514 Duluth, MN 55802, United States Telephone: (218) 722-7724 Fax: (218) 720-6707 Internet: http://www.taconite.org/
JTS	Japan Titanium Society (JTS)	2–9, Kanda Nishiki-Cho, Chiyoda-Ku, Tokyo, ZIP 101, Japan Telephone: 081-3-3295-5958 Fax: 081-3-3293-6187 Internet: http://www.titan-japan.com/
LDA	Lead Development Association International (LDA)	42 Weymount Street, London W1N 3LQ, United Kingdom Telephone: (44) 0171 499 8422 Fax: (44) 0171 493 1555 Internet: http://www.ldaint.org/
MAA	Marble Institute of America (MAA)	28901 Clemens Rd, Ste 100, Cleveland, OH 44145, United States Telephone: (440) 250-9222 Fax: (440) 250-9223 Internet: http://www.marble-institute.com/
MRS	Materials Research Society (MRS)	506 Keystone Drive, Warrendale, PA 15086-7573, United States Telephone: (724) 779-3003 Fax: (724) 779-8313 Internet: http://www.mrs.org/
MTI	Materials Technology Institute (MTI)	1215 Fern Ridge Parkway, Suite 206, St. Louis, MO 63141-4405, United States Telephone: (314) 576-7712 Fax: (314) 576-6078 E-mail: mtiadmin@mti-global.org Internet: http://www.mti-global.org/

Table I.1. *(continued)*

Acronym	Professional Society	Address
MAC	Mineralogical Association of Canada (MAC)	90, rue de la Couronne Québec, (Québec) G1K 9A9 Canada Telephone: (418) 653-0333 Fax: (418) 653-0777 E-mail: office@mineralogicalassociation.ca Internet: http://www.mineralogicalassociation.ca/
MS	Mineralogical Society (MS)	41 Queen's Gate, London SW7 5HR, United Kingdom Telephone: +44 (0)20 7584 7516 Fax: +44 (0)20 7823 8021 E-mail: info@minersoc.org Internet: http://www.minersoc.org/
MSA	Mineralogical Society of America (MSA)	3635 Concorde Pkwy Suite 500 Chantilly, VA 20151-1125 United States Telephone: (703) 652-9950 Fax: (703) 652-9951 E-mail: business@minsocam.org Internet: http://www.minsocam.org/
MES	Minerals Engineering Society (MES)	2 Ryton Close, Blyth, Notts. S81 8DN, United Kingdom Telephone: +44 (0)1909 591787 E-mail: secretary@mineralsengineering.org Internet: http://www.mineralsengineering.org/
MII	Minerals Information Institute (MII)	505 Violet Street Golden, CO 80401 USA Telephone: (303) 277-9190 Fax: (303) 277-9198 E-mail: mii@mii.org Internet: http://www.mii.org/
NACE	National Association of Corrosion Engineers (NACE)	1440 South Creek Drive, Houston, TX 77084-4906, United States Telephone: (281) 228 6200 Fax: (281) 579 6694 Internet: http://www.nace.org/
NIST	National Institute of Standards and Technology (NIST)	100 Bureau Drive, Stop 1070, Gaithersburg, MD 20899-1070, United States Telephone: (301) 975-6478 E-mail: inquiries@nist.gov Internet: http://www.nist.org/
NiDI	Nickel Development Institute (NiDi)	214 King Street West, Suite 510 Toronto Ontario, Canada M5H 3S6 Telephone: (416) 591-7999 Fax: (416) 591-7987 Internet: http://www.nidi.org/
OSA	Optical Society of America (OSA)	2010 Massachusetts Avenue, NW, Washington, DC 20036 United States Telephone: (202) 223 8130 Fax: (202) 223 1096 Internet: http://www.osa.org/

Table I.1. *(continued)*

Acronym	Professional Society	Address
PIA	Plastics Institute of America (PIA)	University of Massachusetts Lowell, 333 Aiken Street, Lowell, MA 01854-3686, United States Telephone: (978) 934-3130 Fax: (978) 458-4141 E-mail: info@plasticsinstitute.org Internet: http://www.plasticsinstitute.org/
PCA	Portland Cement Association (PCA)	5420 Old Orchard Road, Skokie IL 60077 United States Telephone: (847) 966-6200 Fax: (847) 966-8389 Internet: http://www.cement.org/
SI	Salt Institute (SI)	700 N. Fairfax Street, Suite 600 Fairfax Plaza, Alexandria, VA 22314-2040, United States Telephone: (703) 549 4648 Fax: (703) 548 2194 Internet: http://www.saltinstitute.org/
SIC	Scandium Information Center (SIC)	Internet: http://www.scandium.org/
SII	Silver Institue (SII)	The Silver Institute, 1200 G Street, NW Ste. 800 Washington DC 20005, United States Telephone: (202) 835-0185 Fax: (202) 835-0155 E-mail: info@silverinstitute.org Internet: http://www.silverinstitute.org/
SF2M	Société Française de Métallurgie et de Matériaux (SF2M)	250 rue Saint-Jacques, F-75005 Paris, France Telephone: 01 46 33 08 00 Fax: 01 46 33 08 80 Internet: http://www.sf2m.asso.fr/
SFMO	Société Française de Minéralogie et de Cristallographie (SFMC)	Campus Boucicaut, Batiment 7, 140 rue de Lourmel, F-75015 Paris, France Telephone: (+33)01 44 27 60 24 E-mail: sfmc@ccr.jussieu.fr Internet: http://wwwobs.univ-bpclermont.fr/
SAE	Society for Automotive Engineers (SAE)	400, Commonwealth Drive, Warrendale, PA., 15096-0001, United States Telephone: (724) 776-4841 Fax: (724) 776-5760 Internet: http://www.sae.org/
SME	Society of Manufacturing Engineers (SME)	One SME Drive, P.O. Box 930, Dearborn, MI 48121-0930, United States Telephone: (313) 271 1500 Internet: http://www.sme.org/
SME	Society for Mining, Metallurgy, and Exploration (SME)	8307 Shaffer Parkway Littleton, Colorado 80127-4102, United States Telephone: (303) 973-9550 Internet: http://www.smenet.org/
SNAME	Society of Naval Architects and Marine Engineers (SNAME)	601 Pavonia Avenue, Jersey City, NJ 07306 United States Telephone: (201) 798-4800 Fax: (201) 798-4975 Internet: http://www.sname.org/

Table I.1. *(continued)*

Acronym	Professional Society	Address
SPE	Society of Petroleum Engineers (SPE)	P.O. Box 833836, Richardson, TX 75083-3836, United States Telephone: (972) 952-9393 Fax: (972) 952-9435 Internet: http://www.spe.org/
SPI	Society of the Plastics Industry (SPI)	1667 K St., NW, Suite 1000 - Washington, DC 20006 Telephone: (202) 745-200 Fax: (202) 296-7005 Internet: http://www.socplas.org/
SVC	Society of Vacuum Coaters (SVC)	71 Pinon Hill Place N.E., Albuquerque, NM 87122-1407, United States Telephone: (505) 856 7188 Fax: (505) 856 6716 E-mail: svcinfo@svc.org Internet: http://www.svc.org/
SAIMM	South African Institute of Mining and Metallurgy (SAIMM)	P.O. Box 61127, Marshalltown 2107, South Africa Telephone:+27 (011) 834-1273/7 Fax: +27 (011) 838-5923 Internet: http://www.saimm.co.za/
SUI	Sulphur Institute (SUI)	1140 Connecticut Avenue, N.W., Suite 612 Washington, DC 20036, United States Telephone: (202) 331-9660 Fax: (202) 293-2940 E-mail: sulphur@sulphurinstitute.org Internet: http://www.sulphurinstitute.org/
TIC	Tantalum Niobium International Study Center (TIC)	Washington Street, 40, Brussel B-1050 Belgium Telephone: (02) 649 51 58 Fax: (02) 649 64 47 E-mail: tantniob@agoranet.be Internet: http://www.tanb.org/
TMS	The Mineral, Metals, and Materials Society (TMS)	4184 Thorn Hill Road, Warrendale, PA 15086 United States Telephone: (724) 776-9000 Fax: (724) 776-3770 E-mail: robinson@tms.org Internet: http://www.tms.org/
TIG	Titanium Information Group (TIG)	Internet: http://www.titaniuminfogroup.co.uk/
UIC	Uranium Information Centre (UIC)	GPO Box 1649N, Melbourne 3001, Australia Telephone: (03) 9629 7744 Fax (03) 9629 7207 Internet: http://www.uic.com.au
UI	Uranium Institute (UI)	12th Floor, Bowater House West, 114 Knightsbridge, London SW1X 7LJ, UK. Telephone: 44 171 225 0303 Fax: 44 171 225 0308 E-mail: ui@uilondon.org. Internet: http://www.uilondon.org/
USGS	US Geological Survey (USGS)	807 National Center, Reston, VA 20192, USA Internet: http://www.usgs.gov/

Bibliography

In this section only the general references not cited in the previous chapters are listed. For instance, references about semiconductors or superconductors are listed in the corresponding section entitled Further Reading in Chapters 5 and 6 respectively, while general references about metallurgy or comprehensive series in material sciences are listed here.

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