APPENDIX A. PROPERTIES OF THE ELEMENTS

Table 1 lists atomic weights, densities, melting and boiling points, critical points, ionization potentials, specific heats. Data were taken from the 78th edition of the *CRC Handbook of Chemistry and Physics*[1]. Atomic weights apply to elements as they exist naturally on earth, or, in the cases of thorium and protactinium, to the isotopes which have the longest half-lives. Values in parentheses are the mass numbers for the longest lived isotopes of some of the radioactive elements. Specific heats are given for the elements at 25°C. Densities for solids and liquids are given at 25°C, unless otherwise indicated by a superscript temperature (in °C); densities for the gaseous elements are for the liquids at their boiling points.

The solar system elemental abundances (atomic %) in Table 2 are from the compilation of Anders and Grevesse[2], and are based on meteorite and solar wind data. The elemental abundances in the earth's crust and in the sea represent the median values of reported measurements.[1,3,4,5] The concentrations of the less abundant elements may vary with location by several orders of magnitude.

Table 1. Chemical Properties

Z	El	Name	Atomic Weight (a.m.u.)	Density (g/cm^3)	Melting point (°C)	Boiling point (°C)	Critical point (°C)	Ionization potential (eV)	Specific heat (J/g K)
1	H	Hydrogen	1.00794 *7*	0.0708	-259.34	-252.87	-240.18	13.598	14.304
2	He	Helium	4.002602 *2*	0.124901	-272.2	-268.93	-267.96	24.587	5.193
3	Li	Lithium	6.941 *2*	0.534	180.5	1342		5.392	3.582
4	Be	Beryllium	9.012182 *3*	1.85	1287	2471		9.323	1.825
5	B	Boron	10.811 *7*	2.37	2075	4000		8.298	1.026^{amorphous}
6	C	Carbon	12.0107 *8*	2.2670$^{15°}$	4492^{t}	3842^{s}		11.260	0.709^{graphite}
7	N	Nitrogen	14.00674 *7*	0.807	-210.00	-195.79	-146.94	14.534	1.040
8	O	Oxygen	15.9994 *3*	1.141	-218.79	-182.95	-118.56	13.618	0.918
9	F	Fluorine	18.9984032 *5*	1.50	-219.62	-188.12	-129.02	17.423	0.824
10	Ne	Neon	20.1797 *6*	1.204	-248.59	-246.08	-228.7	21.565	1.030
11	Na	Sodium	22.989770 *2*	0.97	97.80	883		5.139	1.228
12	Mg	Magnesium	24.3050 *6*	1.74	650	1090		7.646	1.023
13	Al	Aluminum	26.981538 *2*	2.70	660.32	2519		5.986	0.897
14	Si	Silicon	28.0855 *3*	2.3296	1414	3265		8.152	0.705
15	P	Phosphorus	30.973761 *2*	1.82	44.15	280.5	721	10.487	0.769^{white}
16	S	Sulfur	32.066 *6*	2.067	115.21	444.60	1041	10.360	0.710^{orthorhombic}
17	Cl	Chlorine	35.4527 *9*	1.56	-101.5	-34.04	143.8	12.968	0.479
18	Ar	Argon	39.948 *1*	1.396	-189.35	-185.85	-122.28	15.760	0.520
19	K	Potassium	39.0983 *1*	0.89	63.38	759		4.341	0.757
20	Ca	Calcium	40.078 *4*	1.54	842	1484		6.113	0.647
21	Sc	Scandium	44.955910 *8*	2.99	1541	2836		6.561	0.568
22	Ti	Titanium	47.867 *1*	4.5	1668	3287		6.828	0.523
23	V	Vanadium	50.9415 *1*	6.0	1910	3407		6.746	0.489
24	Cr	Chromium	51.9961 *6*	7.15	1907	2671		6.767	0.449
25	Mn	Manganese	54.938049 *9*	7.3	1246	2061		7.434	0.479
26	Fe	Iron	55.845 *2*	7.875	1538	2861		7.902	0.449
27	Co	Cobalt	58.933200 *9*	8.86	1495	2927		7.881	0.421
28	Ni	Nickel	58.6934 *2*	8.912	1455	2913		7.640	0.444
29	Cu	Copper	63.546 *3*	8.933	1084.62	2562		7.726	0.385

[1] *Handbook of Chemistry and Physics*, 78th edition, D.R. Lide, editor, CRC Press, Boca Raton, FL (1997).

[2] E. Anders and N. Grevesse, *Geochimica et Cosmochimica Acta* **53**, 197 (1989).

[3] *CRC Practical Handbook of Physical Properties of Rocks and Minerals*, R.S. Carmichael, editor, CRC Press, Boca Raton, FL (1989).

[4] I. Bodek *et al*, *Environmental Inorganic Chemistry*, Pergamon Press, New York (1988).

[5] A.B. Ronov and A.A. Yaroshevsky, "Earth's Crust Geochemistry", in the *Encyclopedia of Geochemistry and Environmental Sciences*, R.W. Fairbridge, editor, Van Nostrand, New York (1969).

Z	El	Name	Atomic Weight (a.m.u.)	Density (g/cm^3)	Melting point (°C)	Boiling point (°C)	Critical point (°C)	Ionization potential (eV)	Specific heat (J/g K)
30	Zn	Zinc	65.39 *2*	7.134	419.53	907		9.394	0.388
31	Ga	Gallium	69.723 *1*	5.91	29.76	2204		5.999	0.371
32	Ge	Germanium	72.61 *2*	5.323	938.25	2833		7.900	0.320
33	As	Arsenic	74.92160 *2*	5.776$^{26°}$	817^{t}	614^{s}	1400	9.815	0.329
34	Se	Selenium	78.96 *3*	4.809$^{26°}$	221	685	1493	9.752	0.321
35	Br	Bromine	79.904 *1*	3.11	-7.2	58.8	315	11.814	0.226
36	Kr	Krypton	83.80 *1*	2.418	-157.36	-153.22	-63.74	14.000	0.248
37	Rb	Rubidium	85.4678 *3*	1.53	39.31	688		4.177	0.363
38	Sr	Strontium	87.62 *1*	2.64	777	1382		5.695	0.301
39	Y	Yttrium	88.90585 *2*	4.47	1522	3345		6.217	0.298
40	Zr	Zirconium	91.224 *2*	6.52	1855	4409		6.634	0.278
41	Nb	Niobium	92.90638 *2*	8.57	2477	4744		6.759	0.265
42	Mo	Molybdenum	95.94 *1*	10.2	2623	4639		7.092	0.251
43	Tc	Technetium	[98]	11	2157	4265		7.28	
44	Ru	Ruthenium	101.07 *2*	12.1	2334	4150		7.361	0.238
45	Rh	Rhodium	102.90550 *2*	12.4	1964	3695		7.459	0.243
46	Pd	Palladium	106.42 *1*	12.0	1554.9	2963		8.337	0.244
47	Ag	Silver	107.8682 *2*	10.501	961.78	2162		7.576	0.235
48	Cd	Cadmium	112.411 *8*	8.69	321.07	767		8.994	0.232
49	In	Indium	114.818 *3*	7.31	156.60	2072		5.786	0.233
50	Sn	Tin	118.710 *7*	7.287$^{26°}$	231.93	2602		7.344	0.228^{white}
51	Sb	Antimony	121.760 *1*	6.685$^{26°}$	630.63	1587		8.64	0.207
52	Te	Tellurium	127.60 *3*	6.232	449.51	988		9.010	0.202
53	I	Iodine	126.90447 *3*	4.93$^{20°}$	113.7	184.4	546	10.451	0.145
54	Xe	Xenon	131.29 *2*	2.953	-111.75	-108.04	16.58	12.130	0.158
55	Cs	Cesium	132.90545 *2*	1.93	28.44	671		3.894	0.242
56	Ba	Barium	137.327 *7*	3.62	727	1897		5.212	0.204
57	La	Lanthanum	138.9055 *2*	6.15	918	3464		5.577	0.195
58	Ce	Cerium	140.116 *1*	8.16	798	3443		5.539	0.192
59	Pr	Praseodymium	140.90765 *2*	6.77	931	3520		5.464	0.193
60	Nd	Neodymium	144.24 *3*	7.01	1021	3074		5.525	0.190
61	Pm	Promethium	[145]	7.26	1042	3000		5.55	
62	Sm	Samarium	150.36 *3*	7.52	1074	1794		5.644	0.197
63	Eu	Europium	151.964 *1*	5.24	822	1596		5.670	0.182
64	Gd	Gadolinium	157.25 *3*	7.90	1313	3273		6.150	0.236
65	Tb	Terbium	158.92534 *2*	8.23	1356	3230		5.864	0.182
66	Dy	Dysprosium	162.50 *3*	8.55	1412	2567		5.939	0.173
67	Ho	Holmium	164.93032 *2*	8.80	1474	2700		6.022	0.165
68	Er	Erbium	167.26 *3*	9.07	1529	2868		6.108	0.168
69	Tm	Thulium	168.93421 *2*	9.32	1545	1950		6.184	0.160
70	Yb	Ytterbium	173.04 *3*	6.90	819	1196		6.254	0.155
71	Lu	Lutetium	174.967 *1*	9.84	1663	3402		5.426	0.154
72	Hf	Hafnium	178.49 *2*	13.3	2233	4603		6.825	0.144
73	Ta	Tantalum	180.9479 *1*	16.4	3017	5458		7.89	0.140
74	W	Tungsten	183.84 *1*	19.3	3422	5555		7.98	0.132
75	Re	Rhenium	186.207 *1*	20.8	3186	5596		7.88	0.137
76	Os	Osmium	190.23 *3*	22.5	3033	5012		8.7	0.130
77	Ir	Iridium	192.217 *3*	22.5	2446	4428		9.1	0.131
78	Pt	Platinum	195.078 *2*	21.46	1768.4	3825		9.0	0.133
79	Au	Gold	196.96655 *2*	19.282	1064.18	2856		9.226	0.129
80	Hg	Mercury	200.59 *2*	13.5336	-38.83	356.73	1477	10.438	0.140
81	Tl	Thallium	204.3833 *2*	11.8	304	1473		6.108	0.129
82	Pb	Lead	207.2 *1*	11.342	327.46	1749		7.417	0.129
83	Bi	Bismuth	208.98038 *2*	9.807	271.40	1564		7.289	0.122
84	Po	Polonium	[209]	9.32	254	962		8.417	
85	At	Astatine	[210]		302				

Z	El	Name	Atomic Weight (a.m.u.)	Density (g/cm^3)	Melting point (°C)	Boiling point (°C)	Critical point (°C)	Ionization potential (eV)	Specific heat (J/g K)
86	Rn	Radon	[222]	4.4	-71	-61.7	104	10.749	0.094
87	Fr	Francium	[223]		27				
88	Ra	Radium	[226]	5	700			5.279	
89	Ac	Actinium	[227]	10.07[a]	1051	3198		5.17	
90	Th	Thorium	232.0381 *1*	11.72	1750	4788		6.08	0.113
91	Pa	Protactinium	231.03588 *2*	15.37[a]	1572			5.89	
92	U	Uranium	238.0289 *1*	≈18.95	1135	4131		6.194	0.116
93	Np	Neptunium	[237]	$20.25^{20°}$	644			6.266	
94	Pu	Plutonium	[244]	19.84	640	3228		6.06	
95	Am	Americium	[243]	$13.69^{20°}$	1176	2011		5.993	
96	Cm	Curium	[247]	13.51[a]	1345			6.02	
97	Bk	Berkelium	[247]	14[b]	1050			6.23	
98	Cf	Californium	[251]		900			6.30	
99	Es	Einsteinium	[252]		860			6.42	
100	Fm	Fermium	[257]		1527			6.50	
101	Md	Mendelevium	[258]		827			6.58	
102	No	Nobelium	[259]		827			6.65	
103	Lr	Lawrencium	[262]		1627				
104	Rf	Rutherfordium	[261]						
105	Ha	Hahnium	[262]						
106	Sg	Seaborgium	[266]						
107	Ns	Nielsbohrium	[264]						
108	Hs	Hassium	[269]						
109	Mt	Meitnerium	[268]						
110	??	Element-110	[271]						
111	??	Element-111	[272]						
112	??	Element-112	[277]						

[a]Calculated [b]Estimated [t]Critical temperature [s]Sublimation temperature

Table 2. Elemental Abundances

Z	El	Solar System (%)	Abundance in the Earth's Crust (mg/kg)	Abundance in the Earth's Sea (mg/L)
1	H	91.0 *23*	1400	1.08×10^{5}
2	He	8.9 *5*	0.008	7×10^{-6}
3	Li	1.86×10^{-7} *17*	20	0.18
4	Be	2.38×10^{-9} *23*	2.8	5.6×10^{-6}
5	B	6.9×10^{-8} *7*	10	4.44
6	C	0.033	200	28
7	N	0.0102	19	0.5
8	O	0.078 *8*	4.61×10^{5}	8.57×10^{5}
9	F	2.7×10^{-6} *4*	585	1.3
10	Ne	0.0112 *16*	0.005	1.2×10^{-4}
11	Na	0.000187 *13*	2.36×10^{4}	1.08×10^{4}
12	Mg	0.00350 *13*	2.33×10^{4}	1290
13	Al	0.000277 *10*	8.23×10^{4}	0.002
14	Si	0.00326 *14*	2.82×10^{5}	2.2
15	P	3.4×10^{-5} *3*	1050	0.06
16	S	0.00168 *22*	350	905
17	Cl	1.7×10^{-5} *3*	145	1.94×10^{4}
18	Ar	0.000329 *20*	3.5	0.45
19	K	1.23×10^{-5} *9*	2.09×10^{4}	399
20	Ca	0.000199 *14*	4.15×10^{4}	412
21	Sc	1.12×10^{-7} *10*	22	6×10^{-7}
22	Ti	7.8×10^{-6} *4*	5650	0.001
23	V	9.6×10^{-7} *5*	120	0.0025
24	Cr	4.4×10^{-5} *3*	102	3×10^{-4}
25	Mn	3.1×10^{-5} *3*	950	2×10^{-4}
26	Fe	0.00294 *8*	5.63×10^{4}	0.002
27	Co	7.3×10^{-6} *5*	25	2×10^{-5}
28	Ni	0.000161 *8*	84	5.6×10^{-4}
29	Cu	1.70×10^{-6} *19*	60	2.5×10^{-4}
30	Zn	4.11×10^{-6} *18*	70	0.0049
31	Ga	1.23×10^{-7} *8*	19	3×10^{-5}
32	Ge	3.9×10^{-7} *4*	1.5	5×10^{-5}
33	As	2.1×10^{-8} *3*	1.8	0.0037
34	Se	2.03×10^{-7} *13*	0.05	2×10^{-4}
35	Br	3.8×10^{-8} *7*	2.4	67.3
36	Kr	1.5×10^{-7} *3*	1×10^{-4}	2.1×10^{-4}
37	Rb	2.31×10^{-8} *15*	90	0.12
38	Sr	7.7×10^{-8} *6*	370	7.9
39	Y	1.51×10^{-8} *9*	33	1.3×10^{-5}
40	Zr	3.72×10^{-8} *24*	165	3×10^{-5}
41	Nb	2.28×10^{-9} *3*	20	1×10^{-5}
42	Mo	8.3×10^{-9} *5*	1.2	0.01
43	Tc			
44	Ru	6.1×10^{-9} *3*	0.001	7×10^{-7}
45	Rh	1.12×10^{-9} *9*	0.001	
46	Pd	4.5×10^{-9} *3*	0.015	
47	Ag	1.58×10^{-9} *5*	0.075	4×10^{-5}
48	Cd	5.3×10^{-9} *3*	0.15	1.1×10^{-4}
49	In	6.0×10^{-10} *4*	0.25	0.02
50	Sn	1.25×10^{-8} *12*	2.3	4×10^{-6}
51	Sb	1.01×10^{-9} *18*	0.2	2.4×10^{-4}
52	Te	1.57×10^{-8} *16*	0.001	
53	I	2.9×10^{-9} *6*	0.45	0.06
54	Xe	1.5×10^{-8} *3*	3×10^{-5}	5×10^{-5}
55	Cs	1.21×10^{-9} *7*	3	3×10^{-4}
56	Ba	1.46×10^{-8} *9*	425	0.013
57	La	1.45×10^{-9} *3*	39	3.4×10^{-6}
58	Ce	3.70×10^{-9} *6*	66.5	1.2×10^{-6}
59	Pr	5.44×10^{-10} *13*	9.2	6.4×10^{-7}
60	Nd	2.70×10^{-9} *4*	41.5	2.8×10^{-6}
61	Pm			
62	Sm	8.42×10^{-10} *11*	7.05	4.5×10^{-7}
63	Eu	3.17×10^{-10} *5*	2.0	1.3×10^{-7}
64	Gd	1.076×10^{-9} *15*	6.2	7×10^{-7}
65	Tb	1.97×10^{-10} *4*	1.2	1.4×10^{-7}
66	Dy	1.286×10^{-9} *18*	5.2	9.1×10^{-7}
67	Ho	2.90×10^{-10} *7*	1.3	2.2×10^{-7}
68	Er	8.18×10^{-10} *11*	3.5	8.7×10^{-7}
69	Tm	1.23×10^{-10} *3*	0.52	1.7×10^{-7}
70	Yb	8.08×10^{-10} *13*	3.2	8.2×10^{-7}
71	Lu	1.197×10^{-10} *16*	0.8	1.5×10^{-7}
72	Hf	5.02×10^{-10} *10*	3.0	7×10^{-6}
73	Ta	6.75×10^{-11} *12*	2.0	2×10^{-6}
74	W	4.34×10^{-10} *22*	1.25	1×10^{-4}
75	Re	1.69×10^{-10} *16*	7×10^{-4}	4×10^{-6}
76	Os	2.20×10^{-9} *14*	0.0015	
77	Ir	2.16×10^{-9} *13*	0.001	
78	Pt	4.4×10^{-9} *3*	0.005	
79	Au	6.1×10^{-10} *9*	0.004	4×10^{-6}
80	Hg	1.11×10^{-9} *13*	0.085	3×10^{-5}
81	Tl	6.0×10^{-10} *6*	0.85	1.9×10^{-5}
82	Pb	1.03×10^{-8} *8*	14	3×10^{-5}
83	Bi	4.7×10^{-10} *4*	0.0085	2×10^{-5}
84	Po		2×10^{-10}	1.5×10^{-14}
85	At			
86	Rn		4×10^{-13}	6×10^{-16}
87	Fr			
88	Ra		9×10^{-7}	8.9×10^{-11}
89	Ac		5.5×10^{-10}	
90	Th	1.09×10^{-10} *6*	9.6	1×10^{-6}
91	Pa		1.4×10^{-6}	5×10^{-11}
92	U	2.94×10^{-11} *25*	2.7	0.0032