Appendix B

Tables

1. PHYSICAL CONSTANTS

Table 1.1. Reviewed 2005 by P.J. Mohr and B.N. Taylor (NIST). Based mainly on the "CODATA Recommended Values of the Fundamental Physical Constants: 2002" by P.J. Mohr and B.N. Taylor, Rev. Mod. Phys. **77**, 1 (2005). The last group of constants (beginning with the Fermi coupling constant) comes from the Particle Data Group. The figures in parentheses after the values give the 1-standard-deviation uncertainties in the last digits; the corresponding fractional uncertainties in parts per 10^9 (ppb) are given in the last column. This set of constants (aside from the last group) is recommended for international use by CODATA (the Committee on Data for Science and Technology). The full 2002 CODATA set of constants may be found at `http://physics.nist.gov/constants`

Quantity	Symbol, equation	Value	Uncertainty (ppb)
speed of light in vacuum	c	299 792 458 m s^{-1}	exact*
Planck constant	h	6.626 0693(11)$\times10^{-34}$ J s	170
Planck constant, reduced	$\hbar \equiv h/2\pi$	1.054 571 68(18)$\times10^{-34}$ J s	170
		= 6.582 119 15(56)$\times10^{-22}$ MeV s	85
electron charge magnitude	e	1.602 176 53(14)$\times10^{-19}$ C = 4.803 204 41(41)$\times10^{-10}$ esu	85, 85
conversion constant	$\hbar c$	197.326 968(17) MeV fm	85
conversion constant	$(\hbar c)^2$	0.389 379 323(67) GeV^2 mbarn	170
electron mass	m_e	0.510 998 918(44) MeV/c^2 = 9.109 3826(16)$\times10^{-31}$ kg	86, 170
proton mass	m_p	938.272 029(80) MeV/c^2 = 1.672 621 71(29)$\times10^{-27}$ kg	86, 170
		= 1.007 276 466 88(13) u = 1836.152 672 61(85) m_e	0.13, 0.46
deuteron mass	m_d	1875.612 82(16) MeV/c^2	86
unified atomic mass unit (u)	(mass ^{12}C atom)/12 = (1 g)/(N_A mol)	931.494 043(80) MeV/c^2 = 1.660 538 86(28)$\times10^{-27}$ kg	86, 170
permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$	8.854 187 817 ... $\times10^{-12}$ F m^{-1}	exact
permeability of free space	μ_0	$4\pi\times10^{-7}$ N A^{-2} = 12.566 370 614 ... $\times10^{-7}$ N A^{-2}	exact
fine-structure constant	$\alpha = e^2/4\pi\epsilon_0\hbar c$	7.297 352 568(24)$\times10^{-3}$ = 1/137.035 999 11(46)†	3.3, 3.3
classical electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	2.817 940 325(28)$\times10^{-15}$ m	10
(e^- Compton wavelength)/2π	$\lambda\!\!\!^{-}_e = \hbar/m_e c = r_e\alpha^{-1}$	3.861 592 678(26)$\times10^{-13}$ m	6.7
Bohr radius ($m_{\mathrm{nucleus}} = \infty$)	$a_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2 = r_e\alpha^{-2}$	0.529 177 2108(18)$\times10^{-10}$ m	3.3
wavelength of 1 eV/c particle	$hc/(1\ \mathrm{eV})$	1.239 841 91(11)$\times10^{-6}$ m	85
Rydberg energy	$hcR_\infty = m_e e^4/2(4\pi\epsilon_0)^2\hbar^2 = m_e c^2\alpha^2/2$	13.605 6923(12) eV	85
Thomson cross section	$\sigma_T = 8\pi r_e^2/3$	0.665 245 873(13) barn	20
Bohr magneton	$\mu_B = e\hbar/2m_e$	5.788 381 804(39)$\times10^{-11}$ MeV T^{-1}	6.7
nuclear magneton	$\mu_N = e\hbar/2m_p$	3.152 451 259(21)$\times10^{-14}$ MeV T^{-1}	6.7
electron cyclotron freq./field	$\omega^e_{\mathrm{cycl}}/B = e/m_e$	1.758 820 12(15)$\times10^{11}$ rad s^{-1} T^{-1}	86
proton cyclotron freq./field	$\omega^p_{\mathrm{cycl}}/B = e/m_p$	9.578 833 76(82)$\times10^{7}$ rad s^{-1} T^{-1}	86
gravitational constant‡	G_N	6.6742(10)$\times10^{-11}$ m^3 kg^{-1} s^{-2}	1.5×10^5
		= 6.7087(10)$\times10^{-39}$ $\hbar c$ $(\mathrm{GeV}/c^2)^{-2}$	1.5×10^5
standard gravitational accel.	g_n	9.806 65 m s^{-2}	exact
Avogadro constant	N_A	6.022 1415(10)$\times10^{23}$ mol^{-1}	170
Boltzmann constant	k	1.380 6505(24)$\times10^{-23}$ J K^{-1}	1800
		= 8.617 343(15)$\times10^{-5}$ eV K^{-1}	1800
molar volume, ideal gas at STP	$N_A k$(273.15 K)/(101 325 Pa)	22.413 996(39)$\times10^{-3}$ m^3 mol^{-1}	1700
Wien displacement law constant	$b = \lambda_{\max}T$	2.897 7685(51)$\times10^{-3}$ m K	1700
Stefan-Boltzmann constant	$\sigma = \pi^2k^4/60\hbar^3c^2$	5.670 400(40)$\times10^{-8}$ W m^{-2} K^{-4}	7000
Fermi coupling constant**	$G_F/(\hbar c)^3$	1.166 37(1)$\times10^{-5}$ GeV^{-2}	9000
weak-mixing angle	$\sin^2\widehat{\theta}(M_Z)$ ($\overline{\mathrm{MS}}$)	0.23122(15)††	6.5×10^5
$W^\pm$ boson mass	m_W	80.403(29) GeV/c^2	3.6×10^5
Z^0 boson mass	m_Z	91.1876(21) GeV/c^2	2.3×10^4
strong coupling constant	$\alpha_s(m_Z)$	0.1176(20)	1.7×10^7

π = 3.141 592 653 589 793 238	e = 2.718 281 828 459 045 235	γ = 0.577 215 664 901 532 861

1 in $\equiv$ 0.0254 m	1 G $\equiv 10^{-4}$ T	1 eV = 1.602 176 53(14) $\times 10^{-19}$ J	kT at 300 K = $[38.681\ 684(68)]^{-1}$ eV
1 Å $\equiv$ 0.1 nm	1 dyne $\equiv 10^{-5}$ N	1 eV/c^2 = 1.782 661 81(15) $\times 10^{-36}$ kg	0 °C $\equiv$ 273.15 K
1 barn $\equiv 10^{-28}$ m^2	1 erg $\equiv 10^{-7}$ J	2.997 924 58 $\times 10^9$ esu = 1 C	1 atmosphere $\equiv$ 760 Torr $\equiv$ 101 325 Pa

* The meter is the length of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second.
† At $Q^2 = 0$. At $Q^2 \approx m_W^2$ the value is $\sim 1/128$.
‡ Absolute lab measurements of G_N have been made only on scales of about 1 cm to 1 m.
** See the discussion in Sec. 10, "Electroweak model and constraints on new physics."
†† The corresponding $\sin^2\theta$ for the effective angle is 0.23152(14).

Table 4.1. Revised 2005 by C.G. Wohl (LBNL) and D.E. Groom (LBNL). Adapted from the Commission on Atomic Weights and Isotopic Abundances, "Atomic Weights of the Elements 1999," Pure and Applied Chemistry **73**, 667 (2001), and G. Audi, A.H. Wapstra, and C. Thibault, Nucl. Phys. **A729**, 337 (2003). The atomic number (top left) is the number of protons in the nucleus. The atomic mass (bottom) is weighted by isotopic abundances in the Earth's surface. Atomic masses are relative to the mass of ^{12}C, defined to be exactly 12 unified atomic mass units (u) (approx. g/mole). Relative isotopic abundances often vary considerably, both in natural and commercial samples; this is reflected in the number of significant figures given. A number in parentheses is the atomic mass of the longest-lived known isotope of that element—no stable isotope exists. The exceptions are Th, Pa, and U, which do have characteristic terrestrial compositions. As of early 2006 element 112 has not been assigned a name, and there are no confirmed elements with Z > 112.

PERIODIC TABLE OF THE ELEMENTS

1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIII	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H Hydrogen 1.00794																	2 He Helium 4.002602
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.0067	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosph. 30.973761	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge German. 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybd. 95.94	43 Tc Technet. (97.907216)	44 Ru Ruthen. 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57–71 Lantha- nides	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (208.982430)	85 At Astatine (209.987148)	86 Rn Radon (222.017578)
87 Fr Francium (223.019736)	88 Ra Radium (226.025410)	89–103 Actinides	104 Rf Rutherford. (261.10877)	105 Db Dubnium (262.1141)	106 Sg Seaborg. (263.1221)	107 Bh Bohrium (262.1246)	108 Hs Hassium (277.1498)	109 Mt Meitner. (268.1387)	110 Ds Darmstadt. (271.1461)	111 Rg Roentgen. (272.1536)	112 (277.1639)						

Series															
Lanthanide series	57 La Lanthan. 138.9055	58 Ce Cerium 140.116	59 Pr Praseodym. 140.90765	60 Nd Neodym. 144.24	61 Pm Prometh. (144.912749)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolin. 157.25	65 Tb Terbium 158.92534	66 Dy Dyspros. 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
Actinide series	89 Ac Actinium (227.027752)	90 Th Thorium 232.038055	91 Pa Protactin. 231.035884	92 U Uranium 238.02891	93 Np Neptunium (237.048173)	94 Pu Plutonium (244.064204)	95 Am Americ. (243.061381)	96 Cm Curium (247.070354)	97 Bk Berkelium (247.070307)	98 Cf Californ. (251.079587)	99 Es Einstein. (252.08298)	100 Fm Fermium (257.085105)	101 Md Mendelev. (258.098431)	102 No Nobelium (259.1010)	103 Lr Lawrenc. (262.1096)

5. ELECTRONIC STRUCTURE OF THE ELEMENTS

Table 5.1. Reviewed 2005 by C.G. Wohl (LBNL). The electronic configurations and the ionization energies are from the NIST database, "Ground Levels and Ionization Energies for the Neutral Atoms," W.C. Martin, A. Musgrove, S. Kotochigova, and J.E. Sansonetti (2003), `http://physics.nist.gov` (select "Physical Reference Data"). The electron configuration for, say, iron indicates an argon electronic core (see argon) plus six $3d$ electrons and two $4s$ electrons. The ionization energy is the least energy necessary to remove to infinity one electron from an atom of the element.

	Element		Electron configuration ($3d^5$ = five $3d$ electrons, *etc.*)		Ground state ${}^{2S+1}L_J$	Ionization energy (eV)
1	H	Hydrogen	$1s$		${}^2S_{1/2}$	13.5984
2	He	Helium	$1s^2$		${}^1S_0$	24.5874
3	Li	Lithium	(He) $2s$		${}^2S_{1/2}$	5.3917
4	Be	Beryllium	(He) $2s^2$		${}^1S_0$	9.3227
5	B	Boron	(He) $2s^2\ 2p$		${}^2P_{1/2}$	8.2980
6	C	Carbon	(He) $2s^2\ 2p^2$		${}^3P_0$	11.2603
7	N	Nitrogen	(He) $2s^2\ 2p^3$		${}^4S_{3/2}$	14.5341
8	O	Oxygen	(He) $2s^2\ 2p^4$		${}^3P_2$	13.6181
9	F	Fluorine	(He) $2s^2\ 2p^5$		${}^2P_{3/2}$	17.4228
10	Ne	Neon	(He) $2s^2\ 2p^6$		${}^1S_0$	21.5645
11	Na	Sodium	(Ne) $3s$		${}^2S_{1/2}$	5.1391
12	Mg	Magnesium	(Ne) $3s^2$		${}^1S_0$	7.6462
13	Al	Aluminum	(Ne) $3s^2\ 3p$		${}^2P_{1/2}$	5.9858
14	Si	Silicon	(Ne) $3s^2\ 3p^2$		${}^3P_0$	8.1517
15	P	Phosphorus	(Ne) $3s^2\ 3p^3$		${}^4S_{3/2}$	10.4867
16	S	Sulfur	(Ne) $3s^2\ 3p^4$		${}^3P_2$	10.3600
17	Cl	Chlorine	(Ne) $3s^2\ 3p^5$		${}^2P_{3/2}$	12.9676
18	Ar	Argon	(Ne) $3s^2\ 3p^6$		${}^1S_0$	15.7596
19	K	Potassium	(Ar) $4s$		${}^2S_{1/2}$	4.3407
20	Ca	Calcium	(Ar) $4s^2$		${}^1S_0$	6.1132
21	Sc	Scandium	(Ar) $3d\ 4s^2$	Transition elements	${}^2D_{3/2}$	6.5615
22	Ti	Titanium	(Ar) $3d^2\ 4s^2$		${}^3F_2$	6.8281
23	V	Vanadium	(Ar) $3d^3\ 4s^2$		${}^4F_{3/2}$	6.7462
24	Cr	Chromium	(Ar) $3d^5\ 4s$		${}^7S_3$	6.7665
25	Mn	Manganese	(Ar) $3d^5\ 4s^2$		${}^6S_{5/2}$	7.4340
26	Fe	Iron	(Ar) $3d^6\ 4s^2$		${}^5D_4$	7.9024
27	Co	Cobalt	(Ar) $3d^7\ 4s^2$		${}^4F_{9/2}$	7.8810
28	Ni	Nickel	(Ar) $3d^8\ 4s^2$		${}^3F_4$	7.6398
29	Cu	Copper	(Ar) $3d^{10}\ 4s$		${}^2S_{1/2}$	7.7264
30	Zn	Zinc	(Ar) $3d^{10}\ 4s^2$		${}^1S_0$	9.3942
31	Ga	Gallium	(Ar) $3d^{10}\ 4s^2\ 4p$		${}^2P_{1/2}$	5.9993
32	Ge	Germanium	(Ar) $3d^{10}\ 4s^2\ 4p^2$		${}^3P_0$	7.8994
33	As	Arsenic	(Ar) $3d^{10}\ 4s^2\ 4p^3$		${}^4S_{3/2}$	9.7886
34	Se	Selenium	(Ar) $3d^{10}\ 4s^2\ 4p^4$		${}^3P_2$	9.7524
35	Br	Bromine	(Ar) $3d^{10}\ 4s^2\ 4p^5$		${}^2P_{3/2}$	11.8138
36	Kr	Krypton	(Ar) $3d^{10}\ 4s^2\ 4p^6$		${}^1S_0$	13.9996
37	Rb	Rubidium	(Kr) $5s$		${}^2S_{1/2}$	4.1771
38	Sr	Strontium	(Kr) $5s^2$		${}^1S_0$	5.6949
39	Y	Yttrium	(Kr) $4d\ 5s^2$	Transition elements	${}^2D_{3/2}$	6.2173
40	Zr	Zirconium	(Kr) $4d^2\ 5s^2$		${}^3F_2$	6.6339
41	Nb	Niobium	(Kr) $4d^4\ 5s$		${}^6D_{1/2}$	6.7589
42	Mo	Molybdenum	(Kr) $4d^5\ 5s$		${}^7S_3$	7.0924
43	Tc	Technetium	(Kr) $4d^5\ 5s^2$		${}^6S_{5/2}$	7.28
44	Ru	Ruthenium	(Kr) $4d^7\ 5s$		${}^5F_5$	7.3605
45	Rh	Rhodium	(Kr) $4d^8\ 5s$		${}^4F_{9/2}$	7.4589
46	Pd	Palladium	(Kr) $4d^{10}$		${}^1S_0$	8.3369
47	Ag	Silver	(Kr) $4d^{10}\ 5s$		${}^2S_{1/2}$	7.5762
48	Cd	Cadmium	(Kr) $4d^{10}\ 5s^2$		${}^1S_0$	8.9938

49	In	Indium	(Kr) $4d^{10}5s^2\ 5p$		$^2P_{1/2}$	5.7864
50	Sn	Tin	(Kr) $4d^{10}5s^2\ 5p^2$		$^3P_0$	7.3439
51	Sb	Antimony	(Kr) $4d^{10}5s^2\ 5p^3$		$^4S_{3/2}$	8.6084
52	Te	Tellurium	(Kr) $4d^{10}5s^2\ 5p^4$		$^3P_2$	9.0096
53	I	Iodine	(Kr) $4d^{10}5s^2\ 5p^5$		$^2P_{3/2}$	10.4513
54	Xe	Xenon	(Kr) $4d^{10}5s^2\ 5p^6$		$^1S_0$	12.1298
55	Cs	Cesium	(Xe) $6s$		$^2S_{1/2}$	3.8939
56	Ba	Barium	(Xe) $6s^2$		$^1S_0$	5.2117
57	La	Lanthanum	(Xe) $5d\ 6s^2$	Lanthanides	$^2D_{3/2}$	5.5769
58	Ce	Cerium	(Xe) $4f\ 5d\ 6s^2$		$^1G_4$	5.5387
59	Pr	Praseodymium	(Xe) $4f^3\ 6s^2$		$^4I_{9/2}$	5.473
60	Nd	Neodymium	(Xe) $4f^4\ 6s^2$		$^5I_4$	5.5250
61	Pm	Promethium	(Xe) $4f^5\ 6s^2$		$^6H_{5/2}$	5.582
62	Sm	Samarium	(Xe) $4f^6\ 6s^2$		$^7F_0$	5.6437
63	Eu	Europium	(Xe) $4f^7\ 6s^2$		$^8S_{7/2}$	5.6704
64	Gd	Gadolinium	(Xe) $4f^7\ 5d\ 6s^2$		$^9D_2$	6.1498
65	Tb	Terbium	(Xe) $4f^9\ 6s^2$		$^6H_{15/2}$	5.8638
66	Dy	Dysprosium	(Xe) $4f^{10}\ 6s^2$		$^5I_8$	5.9389
67	Ho	Holmium	(Xe) $4f^{11}\ 6s^2$		$^4I_{15/2}$	6.0215
68	Er	Erbium	(Xe) $4f^{12}\ 6s^2$		$^3H_6$	6.1077
69	Tm	Thulium	(Xe) $4f^{13}\ 6s^2$		$^2F_{7/2}$	6.1843
70	Yb	Ytterbium	(Xe) $4f^{14}\ 6s^2$		$^1S_0$	6.2542
71	Lu	Lutetium	(Xe) $4f^{14}5d\ 6s^2$		$^2D_{3/2}$	5.4259
72	Hf	Hafnium	(Xe) $4f^{14}5d^2\ 6s^2$	Transition elements	$^3F_2$	6.8251
73	Ta	Tantalum	(Xe) $4f^{14}5d^3\ 6s^2$		$^4F_{3/2}$	7.5496
74	W	Tungsten	(Xe) $4f^{14}5d^4\ 6s^2$		$^5D_0$	7.8640
75	Re	Rhenium	(Xe) $4f^{14}5d^5\ 6s^2$		$^6S_{5/2}$	7.8335
76	Os	Osmium	(Xe) $4f^{14}5d^6\ 6s^2$		$^5D_4$	8.4382
77	Ir	Iridium	(Xe) $4f^{14}5d^7\ 6s^2$		$^4F_{9/2}$	8.9670
78	Pt	Platinum	(Xe) $4f^{14}5d^9\ 6s$		$^3D_3$	8.9588
79	Au	Gold	(Xe) $4f^{14}5d^{10}6s$		$2S_{1/2}$	9.2255
80	Hg	Mercury	(Xe) $4f^{14}5d^{10}6s^2$		$^1S_0$	10.4375
81	Tl	Thallium	(Xe) $4f^{14}5d^{10}6s^2\ 6p$		$^2P_{1/2}$	6.1082
82	Pb	Lead	(Xe) $4f^{14}5d^{10}6s^2\ 6p^2$		$^3P_0$	7.4167
83	Bi	Bismuth	(Xe) $4f^{14}5d^{10}6s^2\ 6p^3$		$^4S_{3/2}$	7.2855
84	Po	Polonium	(Xe) $4f^{14}5d^{10}6s^2\ 6p^4$		$^3P_2$	8.414
85	At	Astatine	(Xe) $4f^{14}5d^{10}6s^2\ 6p^5$		$^2P_{3/2}$	
86	Rn	Radon	(Xe) $4f^{14}5d^{10}6s^2\ 6p^6$		$^1S_0$	10.7485
87	Fr	Francium	(Rn) $7s$		$^2S_{1/2}$	4.0727
88	Ra	Radium	(Rn) $7s^2$		$^1S_0$	5.2784
89	Ac	Actinium	(Rn) $6d\ 7s^2$	Actinides	$^2D_{3/2}$	5.17
90	Th	Thorium	(Rn) $6d^2\ 7s^2$		$^3F_2$	6.3067
91	Pa	Protactinium	(Rn) $5f^2\ 6d\ 7s^2$		$^4K_{11/2}$*	5.89
92	U	Uranium	(Rn) $5f^3\ 6d\ 7s^2$		$^5L_6$*	6.1941
93	Np	Neptunium	(Rn) $5f^4\ 6d\ 7s^2$		$^6L_{11/2}$*	6.2657
94	Pu	Plutonium	(Rn) $5f^6\ 7s^2$		$^7F_0$	6.0260
95	Am	Americium	(Rn) $5f^7\ 7s^2$		$^8S_{7/2}$	5.9738
96	Cm	Curium	(Rn) $5f^7\ 6d\ 7s^2$		$^9D_2$	5.9914
97	Bk	Berkelium	(Rn) $5f^9\ 7s^2$		$^6H_{15/2}$	6.1979
98	Cf	Californium	(Rn) $5f^{10}\ 7s^2$		$^5I_8$	6.2817
99	Es	Einsteinium	(Rn) $5f^{11}\ 7s^2$		$^4I_{15/2}$	6.42
100	Fm	Fermium	(Rn) $5f^{12}\ 7s^2$		$^3H_6$	6.50
101	Md	Mendelevium	(Rn) $5f^{13}\ 7s^2$		$^2F_{7/2}$	6.58
102	No	Nobelium	(Rn) $5f^{14}\ 7s^2$		$^1S_0$	6.65
103	Lr	Lawrencium	(Rn) $5f^{14}\ 7s^2\ 7p$?		$^2P_{1/2}$?	4.9?
104	Rf	Rutherfordium	(Rn) $5f^{14}6d^2\ 7s^2$?		$^3F_2$?	6.0?

* The usual *LS* coupling scheme does not apply for these three elements. See the introductory note to the NIST table from which this table is taken.

6. ATOMIC AND NUCLEAR PROPERTIES OF MATERIALS

Table 6.1. Revised May 2002 by D.E. Groom (LBNL). Gases are evaluated at 20°C and 1 atm (in parentheses) or at STP [square brackets]. Densities and refractive indices without parentheses or brackets are for solids or liquids, or are for cryogenic liquids at the indicated boiling point (BP) at 1 atm. Refractive indices are evaluated at the sodium D line. Data for compounds and mixtures are from Refs. 1 and 2. Futher materials and properties are given in Ref. 3 and at `http://pdg.lbl.gov/AtomicNuclearProperties`.

Material	Z	A	$\langle Z/A\rangle$	Nuclear [a] collision length λ_T {g/cm^2}	Nuclear [a] interaction length λ_I {g/cm^2}	$dE/dx\vert_{\min}$ [b] $\left\{\frac{\text{MeV}}{\text{g/cm}^2}\right\}$	Radiation length [c] X_0 {g/cm^2}	{cm}	Density {g/cm^3} ({g/ℓ} for gas)	Liquid boiling point at 1 atm(K)	Refractive index n (($n-1$)×10^6 for gas)
H_2 gas	1	1.00794	0.99212	43.3	50.8	(4.103)	61.28 [d]	(731000)	(0.0838)[0.0899]		[139.2]
H_2 liquid	1	1.00794	0.99212	43.3	50.8	4.034	61.28 [d]	866	0.0708	20.39	1.112
D_2	1	2.0140	0.49652	45.7	54.7	(2.052)	122.4	724	0.169[0.179]	23.65	1.128 [138]
He	2	4.002602	0.49968	49.9	65.1	(1.937)	94.32	756	0.1249[0.1786]	4.224	1.024 [34.9]
Li	3	6.941	0.43221	54.6	73.4	1.639	82.76	155	0.534		—
Be	4	9.012182	0.44384	55.8	75.2	1.594	65.19	35.28	1.848		—
C	6	12.011	0.49954	60.2	86.3	1.745	42.70	18.8	2.265 [e]		—
N_2	7	14.00674	0.49976	61.4	87.8	(1.825)	37.99	47.1	0.8073[1.250]	77.36	1.205 [298]
O_2	8	15.9994	0.50002	63.2	91.0	(1.801)	34.24	30.0	1.141[1.428]	90.18	1.22 [296]
F_2	9	18.9984032	0.47372	65.5	95.3	(1.675)	32.93	21.85	1.507[1.696]	85.24	[195]
Ne	10	20.1797	0.49555	66.1	96.6	(1.724)	28.94	24.0	1.204[0.9005]	27.09	1.092 [67.1]
Al	13	26.981539	0.48181	70.6	106.4	1.615	24.01	8.9	2.70		—
Si	14	28.0855	0.49848	70.6	106.0	1.664	21.82	9.36	2.33		3.95
Ar	18	39.948	0.45059	76.4	117.2	(1.519)	19.55	14.0	1.396[1.782]	87.28	1.233 [283]
Ti	22	47.867	0.45948	79.9	124.9	1.476	16.17	3.56	4.54		—
Fe	26	55.845	0.46556	82.8	131.9	1.451	13.84	1.76	7.87		—
Cu	29	63.546	0.45636	85.6	134.9	1.403	12.86	1.43	8.96		—
Ge	32	72.61	0.44071	88.3	140.5	1.371	12.25	2.30	5.323		—
Sn	50	118.710	0.42120	100.2	163	1.264	8.82	1.21	7.31		—
Xe	54	131.29	0.41130	102.8	169	(1.255)	8.48	2.87	2.953[5.858]	165.1	[701]
W	74	183.84	0.40250	110.3	185	1.145	6.76	0.35	19.3		—
Pt	78	195.08	0.39984	113.3	189.7	1.129	6.54	0.305	21.45		—
Pb	82	207.2	0.39575	116.2	194	1.123	6.37	0.56	11.35		—
U	92	238.0289	0.38651	117.0	199	1.082	6.00	≈0.32	≈18.95		—
Air, (20°C, 1 atm.), [STP]			0.49919	62.0	90.0	(1.815)	36.66	[30420]	(1.205)[1.2931]	78.8	(273) [293]
H_2O			0.55509	60.1	83.6	1.991	36.08	36.1	1.00	373.15	1.33
CO_2 gas			0.49989	62.4	89.7	(1.819)	36.2	[18310]	[1.977]		[410]
CO_2 solid (dry ice)			0.49989	62.4	89.7	1.787	36.2	23.2	1.563	sublimes	—
Shielding concrete [f]			0.50274	67.4	99.9	1.711	26.7	10.7	2.5		—
SiO_2 (fused quartz)			0.49926	66.5	97.4	1.699	27.05	12.3	2.20 [g]		1.458
Dimethyl ether, $(CH_3)_2O$			0.54778	59.4	82.9	—	38.89	—	—	248.7	—
Methane, CH_4			0.62333	54.8	73.4	(2.417)	46.22	[64850]	0.4224[0.717]	111.7	[444]
Ethane, C_2H_6			0.59861	55.8	75.7	(2.304)	45.47	[34035]	0.509(1.356) [h]	184.5	(1.038) [h]
Propane, C_3H_8			0.58962	56.2	76.5	(2.262)	45.20	—	(1.879)	231.1	—
Isobutane, $(CH_3)_2CHCH_3$			0.58496	56.4	77.0	(2.239)	45.07	[16930]	[2.67]	261.42	[1900]
Octane, liquid, $CH_3(CH_2)_6CH_3$			0.57778	56.7	77.7	2.123	44.86	63.8	0.703	398.8	1.397
Paraffin wax, $CH_3(CH_2)_{n\approx 23}CH_3$			0.57275	56.9	78.2	2.087	44.71	48.1	0.93		—
Nylon, type 6 [i]			0.54790	58.5	81.5	1.974	41.84	36.7	1.14		—
Polycarbonate (Lexan) [j]			0.52697	59.5	83.9	1.886	41.46	34.6	1.20		—
Polyethylene terephthlate (Mylar) [k]			0.52037	60.2	85.7	1.848	39.95	28.7	1.39		—
Polyethylene [l]			0.57034	57.0	78.4	2.076	44.64	≈47.9	0.92–0.95		—
Polyimide film (Kapton) [m]			0.51264	60.3	85.8	1.820	40.56	28.6	1.42		—
Lucite, Plexiglas [n]			0.53937	59.3	83.0	1.929	40.49	≈34.4	1.16–1.20		≈1.49
Polystyrene, scintillator [o]			0.53768	58.5	81.9	1.936	43.72	42.4	1.032		1.581
Polytetrafluoroethylene (Teflon) [p]			0.47992	64.2	93.0	1.671	34.84	15.8	2.20		—
Polyvinyltolulene, scintillator [q]			0.54155	58.3	81.5	1.956	43.83	42.5	1.032		—
Aluminum oxide (Al_2O_3)			0.49038	67.0	98.9	1.647	27.94	7.04	3.97		1.761
Barium fluoride (BaF_2)			0.42207	92.0	145	1.303	9.91	2.05	4.89		1.56
Bismuth germanate (BGO) [r]			0.42065	98.2	157	1.251	7.97	1.12	7.1		2.15
Cesium iodide (CsI)			0.41569	102	167	1.243	8.39	1.85	4.53		1.80
Lithium fluoride (LiF)			0.46262	62.2	88.2	1.614	39.25	14.91	2.632		1.392
Sodium fluoride (NaF)			0.47632	66.9	98.3	1.69	29.87	11.68	2.558		1.336
Sodium iodide (NaI)			0.42697	94.6	151	1.305	9.49	2.59	3.67		1.775
Silica Aerogel [s]			0.50093	66.3	96.9	1.740	27.25	136@ρ=0.2	0.04–0.6		1.0+0.21ρ
NEMA G10 plate [t]				62.6	90.2	1.87	33.0	19.4	1.7		—

Material	Dielectric constant ($\kappa = \epsilon/\epsilon_0$) () is ($\kappa$–1)×$10^6$ for gas	Young's modulus [10^6 psi]	Coeff. of thermal expansion [10^{-6}cm/cm-°C]	Specific heat [cal/g-°C]	Electrical resistivity [$\mu\Omega$cm(@°C)]	Thermal conductivity [cal/cm-°C-sec]
H_2	(253.9)	—	—	—	—	—
He	(64)	—	—	—	—	—
Li	—	—	56	0.86	8.55(0°)	0.17
Be	—	37	12.4	0.436	5.885(0°)	0.38
C	—	0.7	0.6–4.3	0.165	1375(0°)	0.057
N_2	(548.5)	—	—	—	—	—
O_2	(495)	—	—	—	—	—
Ne	(127)	—	—	—	—	—
Al	—	10	23.9	0.215	2.65(20°)	0.53
Si	11.9	16	2.8–7.3	0.162	—	0.20
Ar	(517)	—	—	—	—	—
Ti	—	16.8	8.5	0.126	50(0°)	—
Fe	—	28.5	11.7	0.11	9.71(20°)	0.18
Cu	—	16	16.5	0.092	1.67(20°)	0.94
Ge	16.0	—	5.75	0.073	—	0.14
Sn	—	6	20	0.052	11.5(20°)	0.16
Xe	—	—	—	—	—	—
W	—	50	4.4	0.032	5.5(20°)	0.48
Pt	—	21	8.9	0.032	9.83(0°)	0.17
Pb	—	2.6	29.3	0.038	20.65(20°)	0.083
U	—	—	36.1	0.028	29(20°)	0.064

1. R.M. Sternheimer, M.J. Berger, and S.M. Seltzer, Atomic Data and Nuclear Data Tables **30**, 261–271 (1984).
2. S.M. Seltzer and M.J. Berger, Int. J. Appl. Radiat. **33**, 1189–1218 (1982).
3. D.E. Groom, N.V. Mokhov, and S.I. Striganov, "Muon stopping-power and range tables," Atomic Data and Nuclear Data Tables **78**, 183–356 (2001).
4. S.M. Seltzer and M.J. Berger, Int. J. Appl. Radiat. **35**, 665 (1984) & `http://physics.nist.gov/PhysRefData/Star/Text/contents.html`.

a. σ_T, λ_T and λ_I are energy dependent. Values quoted apply to high energy range, where energy dependence is weak. Mean free path between collisions (λ_T) or inelastic interactions (λ_I), calculated from $\lambda^{-1} = N_A \sum w_j\, \sigma_j\, /A_j$, where N is Avogadro's number and w_j is the weight fraction of the jth element in the element, compound, or mixture. $\sigma_{\rm total}$ at 80–240 GeV for neutrons ($\approx \sigma$ for protons) from Murthy *et al.*, Nucl. Phys. **B92**, 269 (1975). This scales approximately as $A^{0.77}$. $\sigma_{\rm inelastic} = \sigma_{\rm total} - \sigma_{\rm elastic} - \sigma_{\rm quasielastic}$; for neutrons at 60–375 GeV from Roberts *et al.*, Nucl. Phys. **B159**, 56 (1979). For protons and other particles, see Carroll *et al.*, Phys. Lett. **80B**, 319 (1979); note that $\sigma_I(p) \approx \sigma_I(n)$. σ_I scales approximately as $A^{0.71}$.

b. For minimum-ionizing muons (results are very slightly different for other particles). Minimum dE/dx from Ref. 3, using density effect correction coefficients from Ref. 1. For electrons and positrons see Ref. 4. Ionization energy loss is discussed in Sec. 27.

c. From Y.S. Tsai, Rev. Mod. Phys. **46**, 815 (1974); X_0 data for all elements up to uranium are given. Corrections for molecular binding applied for H_2 and D_2. For atomic H, $X_0 = 63.05$ g/cm^2.

d. For molecular hydrogen (deuterium). For atomic H, $X_0 = 63.047$ g cm^{-2}.

e. For pure graphite; industrial graphite density may vary 2.1–2.3 g/cm^3.

f. Standard shielding blocks, typical composition O_2 52%, Si 32.5%, Ca 6%, Na 1.5%, Fe 2%, Al 4%, plus reinforcing iron bars. The attenuation length, $\ell = 115 \pm 5$ g/cm^2, is also valid for earth (typical $\rho = 2.15$), from CERN–LRL–RHEL Shielding exp., UCRL–17841 (1968).

g. For typical fused quartz. The specific gravity of crystalline quartz is 2.64.

h. Solid ethane density at −60°C; gaseous refractive index at 0°C, 546 mm pressure.

i. Nylon, Type 6, $(NH(CH_2)_5CO)_n$

j. Polycarbonate (Lexan), $(C_{16}H_{14}O_3)_n$

k. Polyethylene terephthlate, monomer, $C_5H_4O_2$

l. Polyethylene, monomer $CH_2 = CH_2$

m. Polymide film (Kapton), $(C_{22}H_{10}N_2O_5)_n$

n. Polymethylmethacralate, monomer $CH_2 = C(CH_3)CO_2CH_3$

o. Polystyrene, monomer $C_6H_5CH{=}CH_2$

p. Teflon, monomer $CF_2 = CF_2$

q. Polyvinyltolulene, monomer 2-$CH_3C_6H_4CH{=}CH_2$

r. Bismuth germanate (BGO), $(Bi_2O_3)_2(GeO_2)_3$

s. 97% SiO_2 + 3% H_2O by weight; see A. R. Buzykaev *et al.*, Nucl. Instrum. Methods **A433**, 396 (1999). Aerogel in the density range 0.04–0.06 g/cm^3 has been used in Čerenkov counters, but aerogel with higher and lower densities has been produced. ρ = density in g/cm^3.

t. G10-plate, typically 60% SiO_2 and 40% epoxy.