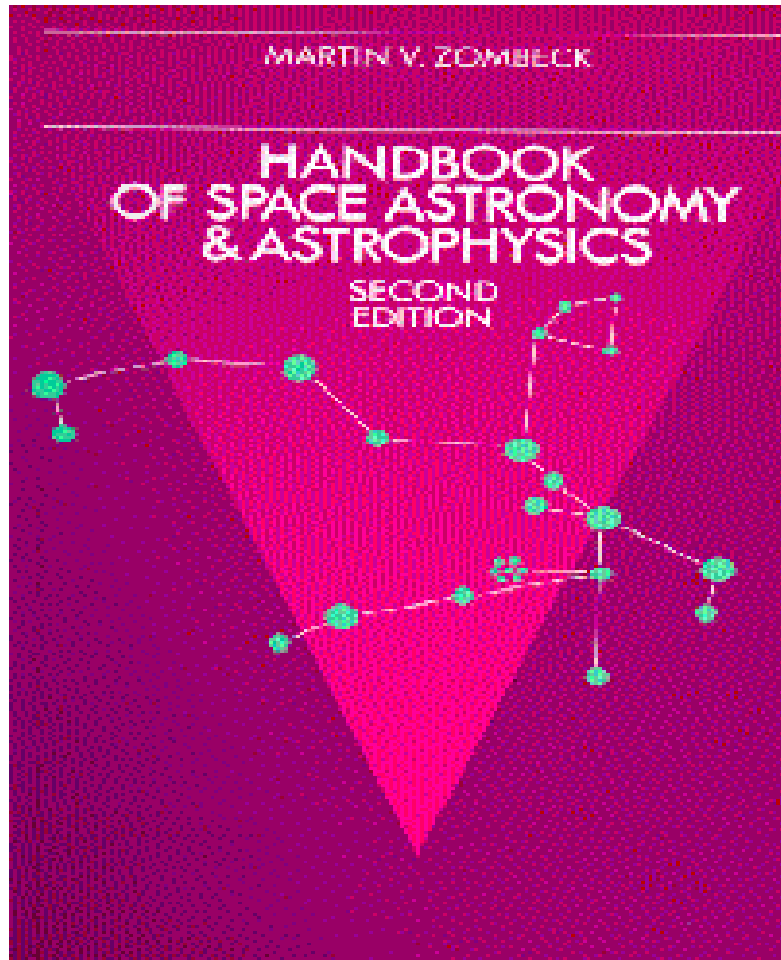


*Cambridge University Press*

# Handbook of Space Astronomy and Astrophysics



**Second Edition**  
**by Martin V. Zombeck**

ISBN 0 521 34550 2 (hardbook)

ISBN 0 521 34787 4 (paperback)

*Dr. Martin V. Zombeck*  
*Smithsonian Astrophysical Observatory*  
*60 Garden Street*  
*Cambridge, MA 02138*  
*USA*



[mvz@cfa.harvard.edu](mailto:mvz@cfa.harvard.edu)

PDF made by © 2003 *Leandro Da Vinci* @ *LEONARDO*

---

# Chapter 1

---

## *General data*

Fundamental physical constants (SI)	2
Fundamental physical constants (c.g.s.)	10
Sun- Earth system constants	10
Cosmological data	11
Unit conversions	11
Conversion tables	12
Numerical constants	16
Mathematical formulae	17
Elementary particles (short list)	17
Elementary particles	18
Energy conversions	19
Prefixes and symbols	19
Periodic table of the elements	20
Greek alphabet	22
Bibliography	22

### Fundamental physical constants (SI)

(1986 recommended values of the fundamental physical constants. The digits in parentheses are the one-standard-deviation uncertainty in the last digits of the given value.)

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
<b>GENERAL CONSTANTS</b>				
<b>UNIVERSAL CONSTANTS</b>				
speed of light in vacuum	$c$	299 792 458	$\text{m s}^{-1}$	(exact)
permeability of vacuum	$\mu_0$	$4\pi \times 10^{-7}$ = 12.566 370 614	$\text{N A}^{-2}$	(exact)
permittivity of vacuum	$\epsilon_0$	$1/4\pi\mu_0 c^2$ = 8.854 187 817 ...	$10^{-12} \text{ F m}^{-1}$	(exact)
Newtonian constant of gravitation	$G$	6.672 59(85)	$10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$	128
Planck constant	$h$	6.626 075 5(40)	$10^{-34} \text{ J s}$	0.60
in electron volts, $h/eV$	$h$	4.135 669 2(12)	$10^{-15} \text{ eV s}$	0.30
$h/2\pi$	$h$	1.054 572 66(63)	$10^{-34} \text{ J s}$	0.60
in electron volts, $h/eV$	$h$	6.582 122 0(20)	$10^{-16} \text{ eV s}$	0.30
Planck mass, $(hc/G)^{1/2}$	$m_P$	2.176 71(14)	$10^{-8} \text{ kg}$	64
Planck length, $(\hbar c/G)^{1/2}$	$l_P$	1.616 16(10)	$10^{-35} \text{ m}$	64
Planck time, $(\hbar c/G)^{1/2}/c$	$t_P$	5.390 56(74)	$10^{-44} \text{ s}$	64
<b>ELECTROMAGNETIC CONSTANTS</b>				
elementary charge	$e$	1.602 177 33(49)	$10^{-19} \text{ C}$	0.30
magnetic flux quantum, $h/2e$	$\Phi_0$	2.067 988 36(72)	$10^{-15} \text{ Wb}$	0.30
Josephson frequency-voltage ratio	$2e/h$	4.835 976 7(14)	$10^{14} \text{ Hz V}^{-1}$	0.30
quantized Hall conductance	$e^2/h$	3.874 046 14(17)	$10^{-3} \text{ S}$	0.145
quantized Hall resistance, $h/e^2 = 3/8g_0 r$	$R_H$	25 812.805 6(12)	$\Omega$	0.145

Bohr magneton, $eh/2m_e$ , in electron volts, $\mu_B/ e $ in hertz, $\mu_B/h$ in wavenumbers, $\mu_B/hc$ in kelvins, $\mu_B/k$	$\mu_B$	9.274 015 4(31) 5.788 382 6(52) 1.599 624 18(42) 46.686 437(14) 0.671 709 9(57)	$10^{-24} \text{ J T}^{-1}$ $10^{-5} \text{ eV T}^{-1}$ $10^{10} \text{ Hz T}^{-1}$ $\text{m}^{-1} \text{ T}^{-1}$ $\text{K T}^{-1}$	0.34 0.089 0.30 0.30 8.5
nuclear magneton, $eh/2m_p$ , in electron volts, $\mu_N/ e $ in hertz, $\mu_N/h$ in wavenumbers, $\mu_N/hc$ in kelvins, $\mu_N/k$	$\mu_N$	5.050 786 6(17) 3.152 451 06(28) 7.622 591 4(23) 2.542 622 8(7.7) 3.658 246(31)	$10^{-27} \text{ J T}^{-1}$ $10^{-8} \text{ eV T}^{-1}$ $\text{MHz T}^{-1}$ $10^{-2} \text{ m}^{-1} \text{ T}^{-1}$ $10^{-4} \text{ K T}^{-1}$	0.34 0.089 0.30 0.30 8.5
<b>ATOMIC CONSTANTS</b>				
<b>ATOM</b>				
fine-structure constant, $\frac{1}{2}m_0c^2/h$ inverse fine-structure constant Rydberg constant, $\frac{1}{2}m_e\alpha^2/h$ in hertz, $R_\infty c$ in joules, $R_\infty hc$ in electron volts, $R_\infty hc/ e $ Bohr radius, $a_0/4\pi R_\infty$ Hartree energy, $e^2/4\pi\epsilon_0 a_0 - 2R_\infty hc$ in electron volts, $E_h/ e $ quantum of circulation	$\alpha$ $\alpha^{-1}$ $R_\infty$  $a_0$ $E_h$ $h/2m_e$ $h/m_e$	7.297 353 08(33) 137.035 989 5(61) 10 973 731.534(13) 3.289 841 949 9(29) 2.179 874 1(12) 13.605 698 1(40) 0.529 177 249(24) 4.359 748 2(261) 27 211 396 1(81) 3.636 948 07(33) 7.273 896 14(65)	$10^{-5}$ $\text{m}^{-1}$ $10^{15} \text{ Hz}$ $10^{-18} \text{ J}$ $\text{eV}$ $10^{10} \text{ m}$ $10^{-18} \text{ J}$ $\text{eV}$ $10^{-4} \text{ m}^2 \text{ s}^{-1}$ $10^{-4} \text{ m}^2 \text{ s}^{-1}$	0.045 0.045 0.0012 0.0012 0.60 0.30 0.045 0.60 0.30 0.089 0.089
<b>ELECTRON</b>				
electron mass in electron volts, $m_e c^2/ e $ electron muon mass ratio electron proton mass ratio electron deuteron mass ratio electron $\alpha$ -particle mass ratio	$m_e$  $m_e/m_\mu$ $m_e/m_p$ $m_e/m_d$ $m_e/m_\alpha$	9.109 389 7(54) 5.485 799 03(13) 0.510 999 06(15) 4.836 332 18(71) 5.446 170 13(11) 2.724 437 07(6) 1.370 933 54(3)	$10^{-31} \text{ kg}$ $10^{-4} \text{ u}$ $\text{MeV}$ $10^{-4}$ $10^{-6}$ $10^{-4}$ $10^{-4}$	0.59 0.023 0.30 0.15 0.020 0.020 0.021

## Fundamental physical constants (SI) (cont.)

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
electron specific charge	$e/m_e$	-1.758 819 62(53)	$10^{11} \text{ C kg}^{-1}$	0.30
electron molar mass	$M(e), M_e$	5.485 799 03(13)	$10^{-3} \text{ kg mol}^{-1}$	0.023
Compton wavelength, $h/m_e c$	$\lambda_C$	2.426 310 56(22)	$10^{-12} \text{ m}$	0.089
$\lambda_C/2\pi = \alpha^{-1}/4\pi R_\infty$	$\lambda_C$	1.861 593 23(35)	$10^{-11} \text{ m}$	0.089
classical electron radius, $\alpha^2 \lambda_C/4\pi$	$r_e$	2.817 940 92(38)	$10^{-17} \text{ m}$	0.13
Thomson cross-section, $(8\pi/3)r_e^2$	$\sigma_T$	0.665 246 16(18)	$10^{-28} \text{ m}^2$	0.27
electron magnetic moment	$\mu_B$	928.477 01(51)	$10^{-26} \text{ JT}^{-1}$	0.34
in Bohr magnetons	$\mu_B/\mu_N$	1.001 159 652 193(10)		$1 \times 10^{-6}$
in nuclear magnetons	$\mu_B/\mu_N$	1836.282 000(37)		0.020
electron magnetic moment anomaly, $\mu_B/\mu_N - 1$	$a_e$	1.159 652 193(10)	$10^{-4}$	0.0086
electron g-factor, $2(1 + a_e)$	$g_e$	2.002 319 304 386(20)		$1 \times 10^{-6}$
electron muon magnetic moment ratio	$\mu_e/\mu_\mu$	206.766 967(30)		0.15
electron proton magnetic moment ratio	$\mu_e/\mu_p$	658.210 658 1(66)		0.010
<b>M C U N</b>				
muon mass	$m_\mu$	1.883 532 7(11)	$10^{-26} \text{ kg}$	0.61
in electron volts, $m_\mu c^2/(e)$		0.113 428 913(17)	e	0.15
muon electron mass ratio	$m_\mu/m_e$	105.658 389(34)	MeV	0.32
muon molar mass	$M(\mu), M_\mu$	206.768 262(30)		0.15
muon magnetic moment	$\mu_\mu$	1.134 289 13(17)	$10^{-24} \text{ kg mol}^{-1}$	0.15
in Bohr magnetons	$\mu_\mu/\mu_B$	4.490 451 4(15)	$10^{-26} \text{ JT}^{-1}$	0.33
in nuclear magnetons	$\mu_\mu/\mu_N$	4.841 970 97(71)	$10^{-3}$	0.15
muon magnetic moment anomaly, $[\mu_\mu/(e\hbar/2m_\mu)] - 1$	$a_\mu$	8.890 598 1(13)	$10^{-3}$	0.15
muon g-factor, $2(1 + a_\mu)$	$g_\mu$	1.165 923 0(84)		7.2
muon proton magnetic moment ratio	$\mu_\mu/\mu_p$	2.002 331 846(17)		0.0084
		3.183 345 47(47)		0.15

**PROTON**

proton mass	$m_p$	1.672 623 1(10)	$10^{-27}$ kg	0.59
in electron volts, $m_p c^2/(e)$		1.007 276 470(12)	u	0.012
proton–electron mass ratio	$m_p/m_e$	938.272 31(28)	MeV	0.30
proton–muon mass ratio	$m_p/m_\mu$	1836.152 70(157)		0.020
proton specific charge	$e/m_p$	6.880 244 4(13)	$10^7$ C kg <sup>-1</sup>	0.15
proton molar mass	$M(p), M_p$	9.576 830 9(39)	$10^{-2}$ kg mol <sup>-1</sup>	0.30
proton Compton wavelength, $h/m_p c$	$\lambda_{C,p}$	1.007 276 470(12)	$10^{-15}$ m	0.012
$\lambda_{C,p}/2\pi$	$\tilde{\lambda}_{C,p}$	1.321 410 02(12)	$10^{-16}$ m	0.089
proton magnetic moment	$\mu_p$	2.103 069 37(19)	$10^{-26}$ J T <sup>-1</sup>	0.089
in Bohr magnetons	$\mu_p/\mu_B$	1.410 607 6(447)	$10^{-2}$	0.34
in nuclear magnetons	$\mu_p/\mu_N$	1.521 032 202(15)		0.010
diamagnetic shielding correction for protons in pure water, spherical sample, 25 °C, $1 - \mu_p/\mu_N$	$\sigma_{H_2O}$	2.792 847 386(63)		0.023
shielded proton moment (H <sub>2</sub> O, sph., 25 °C)	$\mu_p'$	25.689(15)	$10^{-26}$ J T <sup>-1</sup>	0.34
in Bohr magnetons	$\mu_p'/\mu_B$	1.410 571 38(47)	$10^{-2}$	0.011
in nuclear magnetons	$\mu_p'/\mu_N$	1.520 993 129(17)		0.023
proton gyromagnetic ratio	$\gamma_p$	2.792 772 642(64)	$10^4$ s <sup>-1</sup> T <sup>-1</sup>	0.30
in nuclear magnetons	$\gamma_p/2\pi$	26 752.2128(61)	MHz T <sup>-1</sup>	0.30
uncorrected (H <sub>2</sub> O, sph., 25 °C)	$\gamma_p/2\pi$	42.577 469(13)	$10^4$ s <sup>-1</sup> T <sup>-1</sup>	0.30
		26 751.5255(61)	MHz T <sup>-1</sup>	0.30
		42.576 375(13)		0.30

**NEUTRON**

neutron mass	$m_n$	1.674 928 6(10)	$10^{-27}$ kg	0.59
in electron volts, $m_n c^2/(e)$		1.008 664 904(14)	u	0.014
neutron–electron mass ratio	$m_n/m_e$	939.565 63(28)	MeV	0.30
neutron–proton mass ratio	$m_n/m_p$	1838.683 662(40)		0.022
neutron molar mass	$M(n), M_n$	1.001 378 40(49)	$10^{-2}$ kg mol <sup>-1</sup>	0.019
neutron Compton wavelength, $h/m_n c$	$\lambda_{C,n}$	1.008 664 904(14)	$10^{-15}$ m	0.014
$\lambda_{C,n}/2\pi$	$\tilde{\lambda}_{C,n}$	1.319 591 10(12)	$10^{-16}$ m	0.089
		2.100 194 45(19)		0.089

**Fundamental physical constants (SI) (cont.)**

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
neutron magnetic moment <sup>(a)</sup> in Bohr magnetons	$\mu_n$	0.966 237 07(40)	$10^{-26} \text{ J T}^{-1}$	0.41
in nuclear magnetons	$\mu_n/\mu_N$	1.041 875 63(25)	$10^{-3}$	0.24
in nuclear magnetons	$\mu_n/\mu_K$	1.913 042 75(45)		0.24
neutron–electron magnetic moment ratio	$\mu_n/\mu_e$	1.040 668 82(25)	$10^{-2}$	0.24
neutron–proton magnetic moment ratio	$\mu_n/\mu_p$	0.684 979 34(16)		0.24
<b>DEUTERON</b>				
deuteron mass	$m_d$	3.343 586 0(20)	$10^{-27} \text{ kg}$	0.59
		2.013 553 214(24)	u	0.012
		1875.613 39(57)	MeV	0.30
in electron volts, $\mu_N c^2/m_e c^2$	$m_d/m_e$	3670.463 014(75)		0.020
deuteron–electron mass ratio	$m_d/m_e$	1.999 007 496(6)		0.003
deuteron–proton mass ratio	$M(d), M_d$	2.013 553 214(24)	$\text{kg mol}^{-1}$	0.012
deuteron molar mass	$\mu_d$	0.433 073 75(15)	$10^{-26} \text{ J T}^{-1}$	0.34
deuteron magnetic moment <sup>(a)</sup> in Bohr magnetons	$\mu_d/\mu_B$	0.466 975 447 9(91)	$10^{-3}$	0.019
in nuclear magnetons	$\mu_d/\mu_N$	0.857 438 250(24)		0.028
deuteron electron magnetic moment ratio	$\mu_d/\mu_e$	0.466 434 546 0(91)	$10^{-2}$	0.019
deuteron–proton magnetic moment ratio	$\mu_d/\mu_p$	0.387 012 203 5(51)		0.017
<b>PHYSICO-CHEMICAL CONSTANTS</b>				
Avogadro constant	$N_A, L$	6.022 136 7(36)	$10^{23} \text{ mol}^{-1}$	0.59
atomic mass constant, $m_u = \frac{1}{12}m(^{12}\text{C})$	$m_u$	1.660 540 2(10)	$10^{-27} \text{ kg}$	0.59
in electron volts, $m_u c^2/e$		931.494 32(28)	MeV	0.30
Faraday constant	$F$	96 485.309(29)	$\text{C mol}^{-1}$	0.30

molar Planck constant,	$N_A h$	3.990 313 25(26)	$\cdot 10^{-10} \text{ J s mol}^{-1}$	4.0889
molar gas constant	$N_A k_B$	0.119 626 58(11)	$\text{J m mol}^{-1}$	4.0889
Boltzmann constant, $R/N_A$	$R$	8.314 510(30)	$\text{J mol}^{-1} \text{ K}^{-1}$	8.4
in electron volts, $k_B/k_e$	$k$	1.380 658(12)	$10^{-23} \text{ J K}^{-1}$	8.5
in hertz, $k_B/h$		3.161 579(73)	$10^5 \text{ eV K}^{-1}$	8.4
in wavenumbers, $k_B/hc$		2.083 674(18)	$10^{10} \text{ Hz K}^{-1}$	8.4
molar volume (ideal gas), $RT/p$	$V_m$	69.503 87(59)	$\text{m}^3 \cdot \text{K}^{-1}$	8.4
$T = 273.15 \text{ K}$ , $p = 101 325 \text{ Pa}$		22.414 10(19)	$\text{L mol}^{-1}$	8.4
Loschmidt constant, $N_A/V_m$	$\rho_0$	2.686 763(23)	$10^{25} \text{ m}^{-3}$	8.5
$T = 273.15 \text{ K}$ , $p = 100 \text{ kPa}$	$V_m$	22.7118(19)	$\text{L mol}^{-1}$	8.4
Sackur-Tetrode constant (absolute entropy constant), $\frac{5}{2}R + \ln\left\{\frac{2\pi m_0 k_B^3 T_1^3}{h^3 p_0}\right\}$	$S_0^{\circ}R$	1.151 693(21)		18
$T_1 = 1 \text{ K}$ , $p_0 = 100 \text{ kPa}$	$p_0$	1.164 856(21)		18
Stefan Boltzmann constant, $(\pi^5/60)k_B^4/c^2$	$\sigma$	5.670 51(19)	$10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$	14
first radiation constant, $2\pi^5hc^2$	$c_1$	3.741 774 9(27)	$10^{-16} \text{ W m}^2$	0.60
second radiation constant, $hc/k_B$	$c_2$	0.014 387 69(12)	$\text{m K}$	8.4
Wien displacement law constant,	$b$	2.897 756(24)	$10^{-3} \text{ m K}$	8.4
$b = \lambda_{\text{max}} T = c_2/4.965 114 23 \dots$				

<sup>10)</sup> The scalar magnitude of the neutron moment is listed here. The neutron magnetic dipole is directed oppositely to that of the proton, and corresponds to the dipole associated with a spinning negative charge distribution. The vector sum,  $\mu_n + \mu_p$ , is approximately satisfied.

<sup>11)</sup> The entropy of an ideal monatomic gas of relative atomic weight  $A$ , is given by

$$S = S_0 + \frac{5}{2}R \ln A - R \ln(p/p_0) + \frac{3}{2}R \ln(T/K),$$



### Fundamental physical constants (SI) (cont.)

#### MAINTAINED UNITS AND STANDARD VALUES

A summary of 'maintained' units and 'standard' values and their relationship to SI units, based on a least-squares adjustment with 17 degrees of freedom. The digits in parentheses are the one-standard-deviation uncertainty in the last digits of the given value.

Quantity	Symbol	Value	Units	Relative uncertainty (ppm)
electron volt, $(e/C)J$ ( $e$ ) J	eV	1.602 177 13(49)	$10^{-19} J$	0.30
(unified) atomic mass unit, $1 u = m_u = \frac{1}{12}m(^{12}C)$	u	1.660 540 2(16)	$10^{-27} kg$	0.59
standard atmosphere	atm	101 325	Pa	(exact)
standard acceleration of gravity	$g_n$	9.806 65	$m s^{-2}$	(exact)
<b>MAINTAINED ELECTRICAL UNITS</b>				
BIPM <sup>(6)</sup> maintained ohm, $\Omega_{Cu-Bi}$	$\Omega_{\text{BIPM}}$	$1 - 1.563(50) \times 10^{-6}$ $= 0.999 998 437(50)$	$\Omega$	0.050
$\Omega_{\text{BIPM}} = \Omega_{Cu-Bi}$ (1 J <sub>ESU</sub> '085)				
drift rate of $\Omega_{Cu-Bi}$	$\frac{d\Omega_{Cu-Bi}}{dt}$	0.0566(15)	$\mu\Omega/a$	—
BIPM maintained volt, $V_{700-M}$ $\equiv 483 594 GHz_z(h/2e)$	$V_{700-M}$	$1 - 7.59(30) \times 10^{-6}$ $- 0.999 992 41(30)$	V	0.30
BIPM maintained ampere, $\Delta_{\text{BIPM}} = V_{700-M}/\Omega_{Cu-Bi}$	$\Delta_{\text{BIPM}}$	$1 - 6.03(30) \times 10^{-6}$ $= 0.999 993 97(30)$	A	0.30
<b>X-RAY STANDARDS</b>				
Cu x-unit: $\lambda(\text{CuK}\alpha_1) \equiv 1537.40(10)$ XU	$\lambda(\text{CuK}\alpha_1)$	1.002 077 89(70)	$10^{-12} m$	0.70
Mo x-unit: $\lambda(\text{MoK}\alpha_1) \equiv 707.831(10)$ XU	$\lambda(\text{MoK}\alpha_1)$	1.002 099 38(45)	$10^{-12} m$	0.45
$\text{\AA}^*$ : $\lambda(\text{W}\text{K}\alpha_1) \equiv 0.209 100 \text{\AA}^*$	$\text{\AA}^*$	1.000 014 51(92)	$10^{-10} m$	0.92

lattice spacing of Si (in vacuum, 22.5 °C) <sup>(a)</sup>	$d_{220}$	0.343 101 96(11)	nm	0.21
$d_{220} = a/\sqrt{8}$	$d_{220}$	0.192 015 540(40)	nm	0.21
molar volume of Si, $M(\text{Si})/\rho(\text{Si}) = N_A a^3/8$	$V_m(\text{Si})$	12.058 817 9(89)	cm <sup>3</sup> mol <sup>-1</sup>	0.74

<sup>(a)</sup> BIPM: Bureau International des Poids et Mesures.

<sup>(b)</sup> The lattice spacing of single-crystal Si can vary by parts in 10<sup>7</sup> depending on the preparation process. Measurements at Physikalisch-Technische Bundesanstalt (PTB) indicate also the possibility of distortions from exact cubic symmetry of the order of 0.2 ppm.

(Reprinted with permission from CODATA Bulletin, Number 63, Cohen, E. Richard & Taylor, B. N., *The 1986 Adjustment of the Fundamental Physical Constants*, Copyright 1987, Pergamon Press, Ltd.)

**Fundamental physical constants (e.g.s.)**

Speed of light in vacuum	$c = 2.99792458 \times 10^{10} \text{ cm s}^{-1}$
Gravitational constant	$G = 6.67259 \times 10^{-8} \text{ dyn cm}^2 \text{ g}^{-2}$
Planck's constant	$h = 6.6260755 \times 10^{-27} \text{ erg s}$
Electron charge	$e = 4.8032068 \times 10^{-10} \text{ esu}$
Mass of electron	$m_e = 9.1093897 \times 10^{-28} \text{ g}$
Mass of proton	$m_p = 1.6726231 \times 10^{-24} \text{ g}$
Mass of neutron	$m_n = 1.6749286 \times 10^{-24} \text{ g}$
Atomic mass unit (amu)	$m_u = 1.6605402 \times 10^{-24} \text{ g}$
Proton-electron mass ratio	$m_p/m_e = 1836.152701$
Fine structure constant	$hc/2\pi e^2 = 1/\alpha = 137.0359895$
Classical electron radius	$e^2/m_e c^2 = r_e = 2.81794092 \times 10^{-13} \text{ cm}$
Bohr radius	$h^2/4\pi^2 m_e e^2 = a_0 = 0.529177249 \times 10^{-8} \text{ cm}$
Electron Compton wavelength	$h/m_e c = \lambda_c = 2.42631058 \times 10^{-10} \text{ cm}$
Rydberg constant	$2\pi^2 m_e e^4 / hc^3 = R_\infty = 10973731534 \text{ cm}^{-1}$
Boltzmann constant	$k = 1.380658 \times 10^{-16} \text{ erg K}^{-1}$
Stefan-Boltzmann constant	$\sigma = 2\pi^5 k^4 / 15 h^3 c^2$ $= 5.67051 \times 10^{-5} \text{ erg cm}^{-2} \text{ K}^{-4} \text{ s}^{-1}$
Thomson cross-section	$8\pi r_e^2/3 = \sigma_T = 0.66524616 \times 10^{-24} \text{ cm}^2$
Bohr magneton	$eh/4\pi m_e = \mu_B = 9.2740154 \times 10^{-21} \text{ gauss cm}^2$

(Based on constants recommended by the 1986 CODATA Committee in previous table.)

**Sun-Earth system constants**

Equatorial radius for Earth	$a_e = 6378.140 \text{ km}$
Dynamical form-factor for Earth	$J_2 = 0.00108263$
Gravity at Earth's surface (mean)	$g_e = 980.7 \text{ cm s}^{-2}$
Ratio of mass of Moon to that of Earth	$\mu = 0.01230002$
Lunar distance (mean)	$3.84401 \times 10^{10} \text{ cm}$
Astronomical unit	$\text{AU} = 1.49597870 \times 10^{13} \text{ cm}$
Mass of the Earth	$M_e = 5.976 \times 10^{27} \text{ g}$
Solar parallax	$\pi_\odot = 8''.794148$
Tropical year (1900.0)	365.242 days $3.1557 \times 10^7 \text{ ephemeris seconds}$
Ephemeris day	86400 ephemeris seconds
Constant of aberration (2000.0)	$K = 20''.49552$
Obliquity of the ecliptic (2000.0)	$\epsilon = 23^\circ 26' 21''.448$
General precession in longitude per Julian century (2000.0)	$p = 5029''.0966$
Constant of nutation (2000.0)	$N = 9''.2055$
Earth's magnetic dipole moment	$M_e = 8.02 \times 10^{22} \text{ Am}^2$
Angular rotation rate of Earth	$\Omega = 7.292115 \times 10^{-5} \text{ rad s}^{-1}$
Average depth of ocean	$H = 3800 \text{ m}$
Flattening of Earth	$1/f = 298.257$

### Cosmological data

Hubble constant	$H_0 = (50-100) \text{ km s}^{-1} \text{ Mpc}^{-1}$ $= (1.6-3.2) \times 10^{-18} \text{ s}^{-1}$
Hubble time	$1/H_0 = (19.6-9.78) \times 10^9 \text{ y}$
Hubble distance	$R = c/H_0 = (6050-3025) \text{ Mpc}$
Critical density	$\rho_c = 3H_0^2/8\pi G$ $= (5-20) \times 10^{-30} \text{ g cm}^{-3}$
Volume	$\frac{4}{3}\pi R^3 = (9-1) \times 10^{17} \text{ Mpc}^3$
Smoothed density of galactic material throughout universe (Allen 1973)	$2 \times 10^{-31} \text{ g cm}^{-3}$ $1 \times 10^{-7} \text{ atom cm}^{-3}$ $3 \times 10^9 M_\odot \text{ Mpc}^{-3}$
Space density of galaxies	$0.02 \text{ Mpc}^{-3}$
Luminous emission from galaxies	$3 \times 10^{46} L_\odot \text{ Mpc}^{-3}$
Mean sky brightness from galaxies	$1.4(b_v = 10) \text{ deg}^{-2}$
Cosmic background thermodynamic temperature	$2.74 \pm 0.09 \text{ K}$
Weak coupling constant	$g_{\text{wk}} = 1.435 \times 10^{-29} \text{ erg cm}^3$

### Unit conversions

1 keV: $hc/E = 12.39854 \times 10^{-8} \text{ cm}$	1 keV = $1.602177 \times 10^{-9} \text{ erg}$
1 keV: $E/h = 2.417965 \times 10^{17} \text{ Hz}$	1 joule = $10^7 \text{ erg}$
1 keV: $E/k = 11.6048 \times 10^6 \text{ K}$	1 calorie = 4.184 joule
1.0 EHz: $h\nu = 4.13571 \text{ keV}$	
1 parsec = 3.261633 light years = $3.085678 \times 10^{18} \text{ cm}$	
1 light year = $9.460530 \times 10^{17} \text{ cm}$	
1 XU = $1.00209 \times 10^{-11} \text{ cm}$	
1 Angstrom = $1 \times 10^{-8} \text{ cm}$	
1 amu: $Mc^2 = 1.49241 \times 10^{-3} \text{ erg} = 931.494 \text{ MeV}$	
760 torr = $1.013 \times 10^9 \text{ dyn cm}^{-2} = 1 \text{ atmos.} = 1.013 \text{ bars} = 1.013 \times 10^5 \text{ Pascals}$	
1 Rayleigh $\equiv (1/4\pi) \times 10^6 \text{ photons cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$	
11. lumet $\text{s}^{-1} = 1.7 \times 10^{11} \text{ erg cm}^{-2} \text{ s}^{-1} (2-6 \text{ keV})$ $= 2.4 \times 10^{11} \text{ erg cm}^{-2} \text{ s}^{-1} (2-10 \text{ keV})$	
1 flux unit $\equiv 10^{-26} \text{ watt m}^{-2} \text{ Hz}^{-1} \equiv 1 \text{ Jansky}$	
1.0 $\mu\text{Jy} = 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ EHz}^{-1}$ $= 0.242 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1} = 1.509 \times 10^{-7} \text{ keV cm}^{-2} \text{ s}^{-1} \text{ keV}^{-1}$	
1 curie: amount of material undergoing $3.7 \times 10^{10}$ disintegrations $\text{s}^{-1}$	
1 nautical mile = 1852 m	
1 statute mile = 1609.344 m	
intensity ( $\text{erg cm}^{-2} \text{ s}^{-1} \text{ Hz}^{-1}$ ) = $3.33 \times 10^{-16} \lambda^2(\text{\AA})$ intensity ( $\text{erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1}$ )	
1 barn = $10^{-24} \text{ cm}^2$	
1 tesla = $10^4$ Gauss	
0 °C = 273.15 K	

### Conversion tables

(A given amount of a physical quantity, expressed in the units of one system, is expressed as an equivalent number of units in another system.)

Quantity	Amount	Unit	Amount	Unit
<b>LENGTH</b>				
	1	meter (SI)	$1.000\ 001\text{E}-02$	centimeter (cgs)
	1	light year	$9.460\ 53\text{E}+15$	meter (SI)
	1	parsec	$3.085\ 68\text{E}+16$	meter (SI)
	1	Angstrom	$1.000\ 01\text{E}-10$	meter (SI)
	1	Angstrom	$1.000\ 01\text{E}-08$	centimeter (cgs)
	1	micron	$1.000\ 001\text{E}-06$	meter (SI)
	1	XU	$1.002\ 09\text{E}-13$	meter (SI)
	1	fermi	$1.000\ 001\text{E}-15$	meter (SI)
	1	nautical mile	$1.852\ 001\text{E}+03$	meter (SI)
	1	statute mile	$1.609\ 34\text{E}+03$	meter (SI)
	1	astron. unit (AU)	$1.495\ 98\text{E}+11$	meter (SI)
	1	solar radius	$6.959\ 30\text{E}+08$	meter (SI)
	1	centimeter (cgs)	$3.240\ 78\text{E}-19$	parsec
	1	centimeter (cgs)	$6.684\ 56\text{E}-14$	astron. unit (AU)
	1	meter (SI)	$3.240\ 78\text{E}-17$	parsec
	1	meter (SI)	$6.684\ 54\text{E}-12$	astron. unit (AU)
	1	inch (Eng)	$2.540\ 001\text{E}-02$	meter (SI)
<b>MASS</b>				
	1	kilogram (SI)	$1.000\ 001\text{E}-03$	gram (cgs)
	1	at. mass unit (amu)	$1.660\ 54\text{E}-24$	gram (cgs)
	1	at. mass unit (amu)	$1.660\ 54\text{E}-27$	kilogram (SI)
	1	solar mass	$1.989\ 10\text{E}+33$	gram (cgs)
	1	solar mass	$1.989\ 10\text{E}+30$	kilogram (SI)

1	gram (cgs) = 6.02214E - 23	at. mass unit (amu)
1	gram (cgs) = 5.027 40E - 34	solar mass
1	kilogram (SI) = 6.022 14E + 26	at. mass unit (amu)
1	kilogram (SI) = 5.027 40E 31	solar mass
1	kilogram (SI) = 2.204 62E + 00	pound (avdp.)
1	kilogram (SI) = 3.527 40E + 01	ounce (avdp.)
1	pound (avdp.) = 4.535 92E 01	kilogram (SI)
1	pound (avdp.) = 1.600 00E + 01	ounce (avdp.)
1	ounce (avdp.) = 2.834 95E + 01	gram (cgs)
1	gram (cgs) = 3.527 40E 02	ounce (avdp.)
<b>ENERGY</b>		
1	joule (SI) = 1.000 00E + 07	erg (cgs)
1	joule (SI) = 6.241 51E + 18	electron volt (eV)
1	erg (cgs) = 1.000 00E - 07	joule (SI)
1	erg (cgs) = 6.241 51E + 11	electron volt
1	electron volt = 1.602 18E - 12	erg (cgs)
1	amu x c <sup>2</sup> = 9.314 95E - 08	electron volt
1	gm (cgs) x c <sup>2</sup> = 5.609 59E + 32	electron volt
1	calorie = 4.184 00E + 00	joule (SI)
<b>FORCE</b>		
1	newton (SI) = 1.000 00E + 05	dyne (cgs)
1	dyne (cgs) = 1.000 00E 05	newton (SI)
<b>PRESSURE</b>		
1	pascal (SI) = 1.000 00E 00	newton m <sup>-2</sup> (SI)
1	bar = 1.000 00E 06	Dyne cm <sup>-2</sup> (cgs)
1	bar = 9.869 23E 01	atmosphere
1	torr = 1.333 22E 03	bar
<b>POWER</b>		
1	watt (SI) = 1.000 00E + 07	erg s <sup>-1</sup> (cgs)
1	horsepower = 7.457 00E + 02	watt (SI)
1	Btus ( (Eng) = 1.055 80E + 03	watt (SI)

## Conversion tables (cont.)

Quantity	Amount	Unit	Amount	Unit
<b>TIME</b>				
	1	second (SI) - 1		second (cgst)
	1	minute = 6.000 00E - 01		second
	1	hour = 3.600 00E - 03		second
	1	day = 8.640 00E - 04		second
	1	tropical year = 3.155 69E - 07		second
	1	tropical year - 3.652 42E - 02		day
	1	second = 3.168 88E - 08		tropical year
	1	sideral second = 9.972 70E - 01		second
	1	sideral year = 3.652 56E - 02		day
<b>TEMPERATURE</b>				
	T	kelvin = T - 273.15		celsius
	T	kelvin = (9/5) / (T - 273.15) - 32		fahrenheit
	T	celsius = T + 273.15		kelvin
	T	fahrenheit = (5/9) × (T - 32) + 273.15		kelvin
	T	celsius = (9/5) × T + 32		fahrenheit
	T	fahrenheit = (5/9) × (T - 32)		celsius
Energy equivalence	1	electron volt: 1.601 48E - 04		kelvin
Temperature equivalence	1	kelvin: 8.617 12E - 05		electron volt
<b>ELECTRICITY AND MAGNETISM</b>				
Charge	1	coulomb - 2.997 92E + 09		statcoulomb
Charge density	1	coulomb m <sup>-3</sup> = 2.997 92E + 03		statcoul cm <sup>-3</sup>
Current	1	ampere (coul s <sup>-1</sup> ) = 2.997 92E + 09		statampere
Current density	1	ampere m <sup>-2</sup> = 2.997 92E + 05		statamp cm <sup>-2</sup>
Electric field	1	volt m <sup>-1</sup> = 3.335 65E - 05		statvolt cm <sup>-1</sup>
Potential	1	volt = 3.335 65E - 03		statvolt

Resistance	ohm = 1.112 65E - 12	$\text{ohm}^{-1}$
Resistivity	ohm m = 1.112 65E - 10	s
Conductance	siemens, mho = 8.987 52E - 11	$\text{ohm}^{-1} \text{m}^{-1}$
Conductivity	mho $\text{m}^{-1}$ = 8.987 52E - 09	$\text{s}^{-1}$
Capacitance	farad = 8.987 52E - 11	cm
Magnetic flux	weber = 1.000 00E - 08	gauss $\cdot\text{cm}^2$ (maxwell)
Magnetic flux density	tesla = 1.000 00E - 04	gauss
Magnetic field	ampere-turn $\text{m}^{-1}$ = 1.256 64E - 02	oersted
Inductance	henry = 1.112 65E - 12	$\text{A}^2 \text{wb}^{-1}$
<b>MISCELLANEOUS</b>		
Radio-activity	curie (SI) = 3.700 00E - 10	disint $\cdot\text{s}^{-1}$
Intensity	rayleigh = 7.957 75E - 04	$\text{ph} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$
Flux density	fu or jansky = 1.000 00E - 26	watt $\text{m}^{-2} \text{Hz}^{-1}$
Flux density	jansky = 1.000 00E - 05	$\text{erg} \text{cm}^{-2} \text{s}^{-1} \text{Hz}^{-1}$
Flux density	jansky = 2.420 00E - 06	$\text{erg} \text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$
Flux density	jansky = 1.509 00E + 03	$\text{keV} \text{cm}^{-2} \text{s}^{-1} \text{keV}^{-1}$
Energy equivalence	eV = 1.239 85E - 04	Angstrom
Energy equivalence	eV = 2.417 97E - 14	Hz
Wavelength equivalence	Angstrom = 1.239 85E + 04	eV
Angle	arcsec = 4.848 14E - 06	radian
Angle	arcmin = 2.908 88E - 04	radian
Angle	degree = 1.745 33E - 02	radian
Solid angle	arcmin $^2$ = 2.550 40E - 11	steradian
Solid angle	arcmin $^2$ = 8.461 70E - 08	steradian
Solid angle	deg $^2$ = 3.046 20E - 04	steradian



## Numerical constants

$\pi = 3.141\,592\,7$	rad = 57.295 78 deg
$e = 2.718\,281\,8$	$= 3.437\,747 \times 10^3$ arcmin
$\ln 2 = 0.693\,147\,2$	$= 2.062\,648 \times 10^5$ arcsec
$\log_{10} 2 = 0.301\,030\,0$	steradian = 32 400/n <sup>2</sup> = 3.2828 × 10 <sup>-4</sup> deg <sup>2</sup>
$\ln 10 = 2.302\,585\,1$	$= 1.1818 \times 10^7$ arcmin <sup>2</sup>
$\log_{10} e = 0.434\,294\,5$	$= 4.2545 \times 10^{10}$ arcsec <sup>2</sup>
$(2\pi)^{1/2} = 2.506\,628$	degree = 0.017 453 3 rad
$\pi^2 = 9.869\,604$	arcmin = 2.908 88 × 10 <sup>-4</sup> rad
$2^{10} = 1024$	arcsec = 4.848 137 × 10 <sup>-5</sup> rad
$e^{-2} = 0.135\,335\,3$	deg <sup>2</sup> = 3.0462 × 10 <sup>-1</sup> steradian
$\Gamma(n+1) = n!$ , integer $n$	arcmin <sup>2</sup> = 8.4617 × 10 <sup>-8</sup> steradian
$\Gamma(1/2) = \pi^{-1/2}$	arcsec <sup>2</sup> = 2.3504 × 10 <sup>-11</sup> steradian
Feigenbaum's number: $\delta = 4.669\,201\,6$	

$n$	Powers of 2:		Number system conversions:			
	$2^n$	$\log 2^n$	Decimal	Octal	Binary	Hexadecimal
0	1	0.00	0	0	0000	0
1	2	0.30	1	1	0001	1
2	4	0.60	2	2	0010	2
3	8	0.90	3	3	0011	3
4	16	1.20	4	4	0100	4
5	32	1.51	5	5	0101	5
6	64	1.81	6	6	0110	6
7	128	2.11	7	7	0111	7
8	256	2.41	8	10	1000	8
9	512	2.71	9	11	1001	9
10	1024	3.01	10	12	1010	A
11	2048	3.31	11	13	1011	B
12	4096	3.61	12	14	1100	C
13	8192	3.91	13	15	1101	D
14	16 384	4.21	14	16	1110	E
15	32 768	4.52	15	17	1111	F
20	1 048 576	6.02	16	20	10000	10
25	33 554 432	7.53				
$n$		0.301n				

### Mathematical formulae

$$(a + x)^n = a^n + na^{n-1}x + \frac{n(n-1)}{2!}a^{n-2}x^2 + \frac{n(n-1)(n-2)}{3!}a^{n-3}x^3 + \dots + na^{n-1}x^{n-1} + x^n,$$

where  $n$  is any positive integer.

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots$$

$$\ln(1+x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} + \dots \text{ for } -1 < x \leq 1.$$

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \dots,$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \dots$$

$$\int u \, dv = uv - \int v \, du + C,$$

$$\int_0^{\pi} \sin^2 nx \, dx = \int_0^{\pi} \cos^2 nx \, dx = \frac{\pi}{2}$$

for an integer,  $n \neq 0$ .

$$\int_0^{\infty} e^{-x^2} dx = \pi^{1/2}/2,$$

$$\int_0^{\infty} x^n e^{-ax} dx = \Gamma(n+1)/a^{n+1}.$$

$$F(u) = \int_{-\infty}^{\infty} f(x) e^{-2\pi iux} dx \leftrightarrow f(x) = \int_{-\infty}^{\infty} h(u) e^{2\pi iux} dx.$$

$$n! \approx (2\pi)^{1/2} n^{n+1/2} e^{-n} \text{ (for large } n).$$

$$\int_a^b f(x) dx = - \int_b^a f(x) dx,$$

$$\int_a^b f(x) dx = \int_a^c f(x) dx + \int_c^b f(x) dx.$$

$$\frac{d}{dx} f[v(x)] = \frac{df}{dv} \frac{dv}{dx},$$

$$\frac{d}{dx} [u(x)v(x)] = v \frac{du}{dx} + u \frac{dv}{dx}.$$

$$\frac{d}{dx} \ln f(x) = f'(x)/f(x).$$

$$2.30 \log_{10} x = \log_e x$$

$$\sin(A+B) = \sin A \cos B + \cos A \sin B.$$

$$\cos(A+B) = \cos A \cos B - \sin A \sin B.$$

$$e^{i\pi} = \cos \pi + i \sin \pi.$$

### Elementary particles (short list)

Particle	Charge	Mass (amu)	Spin	Magnetic moment	Mean life <sup>(a)</sup> (s)
Photon	0	0	1	0	stable
$\pi$ -meson	+1, -1	0.149 84	1	0	$2.60 \times 10^{-8}$
	0	0.144 90	0	0	$0.83 \times 10^{-16}$
Neutrino	0	$< 10^{-6}$	1/2	$\sim 0$	stable
Electron, positron	-1, +1	0.000 548 6	1/2	$1.001 160 \mu_B^{(b)}$	stable
$\mu$ -meson	-1, +1	0.1134	1/2	$0.004 842 \mu_B$	$2.20 \times 10^{-6}$
Proton	+1, -1	1.007 276	1/2	$2.792 85 \mu_N^{(c)}$	stable
Neutron	0	1.008 665	1/2	$-1.913 02 \mu_N$	917 - 14

<sup>(a)</sup> half-life = mean life  $\times \ln 2$

<sup>(b)</sup>  $\mu_B = eh/4\pi m_e c = 9.274 015 4(31) \times 10^{-24} \text{ J T}^{-1}$

<sup>(c)</sup>  $\mu_N = eh/4\pi m_p c = 5.050 736 6(17) \times 10^{-27} \text{ J T}^{-1}$

(Data from 'Reviews of Particle Properties', *Rev. Mod. Phys.* 52, No. 2, April 1980)

## Elementary Particles

(The second column is the isospin  $t$ , while the next column is the spin and parity,  $J^P$ . Masses and lifetimes have generally been rounded; see the original reference for error bars and a complete listing of particle properties.)

Particle	$t$	$J^P$	Mass (MeV)	Mean life (s)
<b>LEPTONS</b>				
$e$		$\frac{1}{2}$	0.511 003	Stable
$\mu$		$\frac{1}{2}$	105.6594	$2.197\ 14 \times 10^{-6}$
$\tau$		$\frac{1}{2}$	1784	$5 \times 10^{-13}$
<b>NONSTRANGE BARYONS</b>				
$p$	$\frac{1}{2}$	$\frac{1}{2}^+$	938.280	Stable
$n$	$\frac{1}{2}$	$\frac{1}{2}^+$	939.573	925
$\Delta$	$\frac{3}{2}$	$\frac{3}{2}^+$	1232	$6 \times 10^{-24}$
<b>STRANGENESS = -1 BARYONS</b>				
$\Lambda$	0	$\frac{1}{2}^+$	1115.60	$2.63 \times 10^{-10}$
$\Sigma^+$	1	$\frac{1}{2}^+$	1189.36	$8.00 \times 10^{-11}$
$\Sigma^0$	1	$\frac{1}{2}^+$	1192.46	$6 \times 10^{-20}$
$\Sigma^-$	1	$\frac{1}{2}^+$	1197.34	$1.48 \times 10^{-10}$
<b>STRANGENESS = -2 BARYONS</b>				
$\Xi^0$	$\frac{1}{2}$	$\frac{1}{2}^+$	1314.9	$2.9 \times 10^{-10}$
$\Xi^-$	$\frac{1}{2}$	$\frac{1}{2}^+$	1321.3	$1.64 \times 10^{-10}$
<b>STRANGENESS = -3 BARYON</b>				
$\Omega^-$	0	$\frac{3}{2}^+$	1672.5	$8.2 \times 10^{-11}$
<b>NONSTRANGE CHARMED BARYON</b>				
$\Lambda_c^+$	0	$\frac{1}{2}^+$	2282	$1 \times 10^{-13}$
<b>NONSTRANGE MESONS</b>				
$\pi^+$	1	$0^-$	139.567	$2.603 \times 10^{-8}$
$\pi^0$	1	$0^-$	134.963	$8.3 \times 10^{-17}$
$\eta$	0	$0^-$	548.8	$8 \times 10^{-16}$
$\rho$	1	$1^-$	769	$4.3 \times 10^{-24}$
$\omega$	0	$1^-$	782.6	$6.6 \times 10^{-23}$
$\eta'$	0	$0^-$	957.6	$2.4 \times 10^{-21}$
$\phi$	0	$1^-$	1019.6	$1.6 \times 10^{-22}$
$J/\Psi$	0	$1^-$	3096.9	$1.0 \times 10^{-20}$
$\Upsilon$		1	9456	$1.6 \times 10^{-20}$
<b>STRANGENESS = -1 MESONS</b>				
$K^+$	$\frac{1}{2}$	0	493.67	$1.237 \times 10^{-8}$
$K^0, \bar{K}^0$	$\frac{1}{2}$	0	497.7	$K_S^0: 8.92 \times 10^{-11}$ $K_L^0: 5.18 \times 10^{-9}$
<b>CHARMED NONSTRANGE MESONS</b>				
$D$	$\frac{1}{2}$	$0^-$	1869.4	$9 \times 10^{-12}$
$D^+, D^0$	$\frac{1}{2}$	$0^-$	1864.7	$5 \times 10^{-13}$
<b>CHARMED STRANGE MESON</b>				
$F^+$	0	$0^-$	2021	$2 \times 10^{-13}$

(From Shapiro, S. L. & Teukolsky, S. A., *Black Holes, White Dwarfs, and Neutron Stars*, John Wiley and Sons, 1983, with permission.)

### Energy conversions

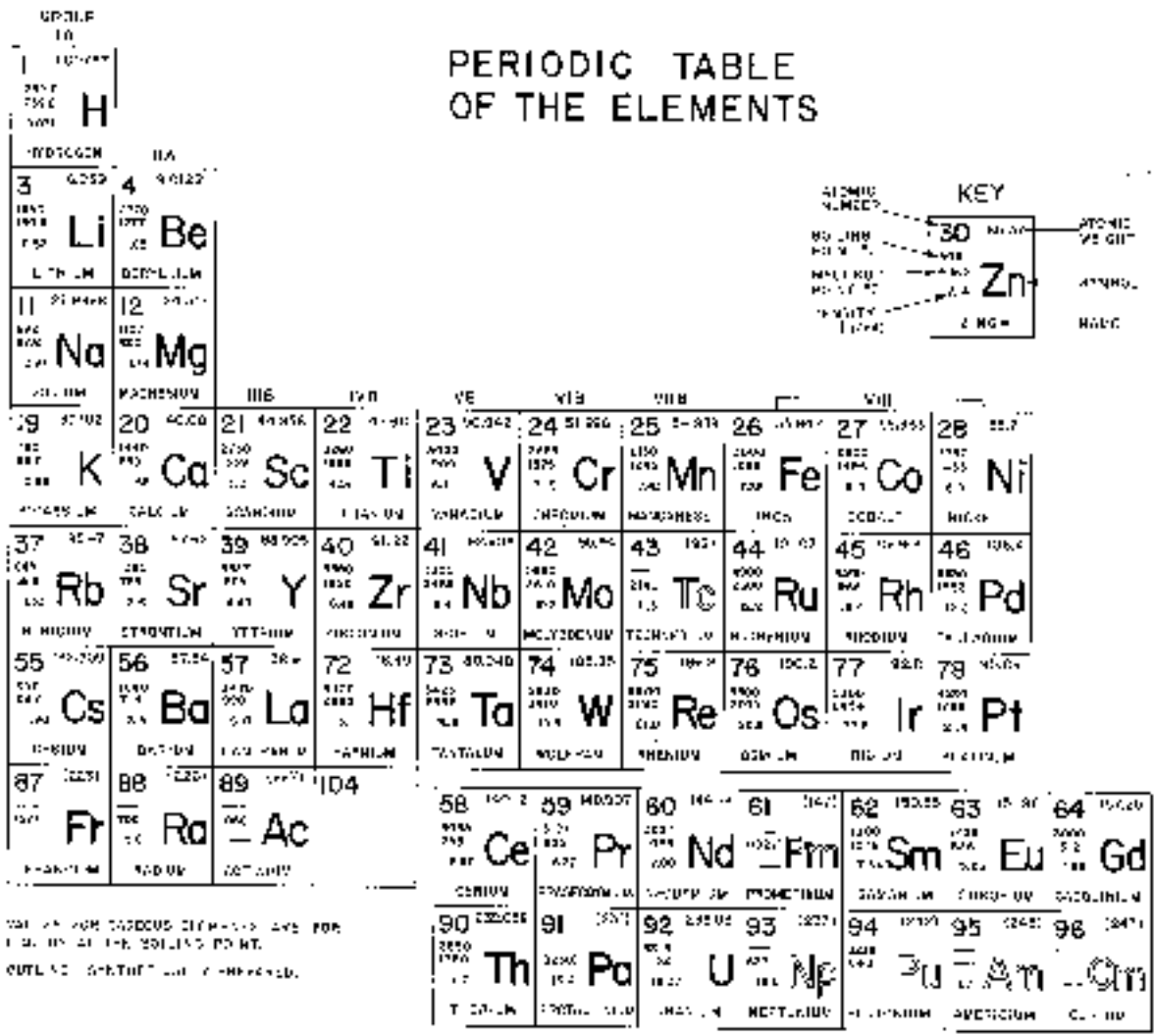
1 erg	= 1 dyne-centimeter = $10^{-7}$ joule
1 joule	= 1 newton-meter
1 foot-pound	= 1.356 joule
1 calorie	= 4.184 joule
1 Btu	= $1.055 \times 10^3$ joule
1 horsepower-hour	= $2.6845 \times 10^8$ joule
1 kilowatt-hour	= $3.6 \times 10^6$ joule = $3.413 \times 10^3$ Btu
1 MeV	= $1.6 \times 10^{-13}$ joule
Energy of fission of 1 atom of $^{235}\text{U}$	= 199 MeV = $3.2 \times 10^{-11}$ joule
Energy equivalent of 1 ton of TNT	= $4.2 \times 10^9$ joule
Energy of fission of 1 kilogram of $^{235}\text{U}$	= 20 kilotons of TNT
Hydrogen fusion:	$D + T \rightarrow \text{He}^4 + n + 17.6 \text{ MeV}$
Energy equivalent of 1 gram of matter	= $9 \times 10^{13}$ joule
High heat value of 1 ton of coal	= $26 \times 10^6$ Btu
High heat value of 1 cord of red oak	= $30 \times 10^6$ Btu
High heat value of 100 gallons of fuel oil	= $15 \times 10^6$ Btu
High heat value of 20 000 cu ft natural gas	= $20 \times 10^6$ Btu
US energy consumption	= $10^{20}$ joule $\text{yr}^{-1}$ (proj. 1970–2000)
Earth's daily receipt of solar energy	= $1.49 \times 10^{22}$ joule = $4.2 \times 10^{12}$ Mwh
Earth's rotational energy	= $2.2 \times 10^{29}$ joule
Earth's total heat content	= $3 \times 10^{31}$ joule
1 D-cell flashlight battery	= 116 watt- $\text{h}$ = $10^2$ joule

### Prefixes and symbols

(used with SI units to indicate decimal multiples and submultiples)

Multiples			Submultiples		
Factor	Prefix	Symbol	Factor	Prefix	Symbol
$10^{18}$	exa	E	$10^{-1}$	deci	d
$10^{15}$	peta	P	$10^{-2}$	centi	c
$10^{12}$	tera	T	$10^{-3}$	milli	m
$10^9$	giga	G	$10^{-6}$	micro	$\mu$
$10^6$	mega	M	$10^{-9}$	nano	n
$10^3$	kilo	k	$10^{-12}$	pico	p
$10^2$	hecto	h	$10^{-15}$	femto	f
10	deca	da	$10^{-18}$	atto	a

Periodic table of the elements



## Periodic table of the elements (cont.)

										VI 14	
										2	4.0026
										He	Helium
										5	10.81
										B	Boron
										6	12.01
										C	Carbon
										7	14.0067
										N	Nitrogen
										8	15.9994
										O	Oxygen
										9	18.9984
										F	Fluorine
										10	20.183
										Ne	Neon
										13	26.9815
										Al	Aluminum
										14	28.086
										Si	Silicon
										15	30.9738
										P	Phosphorus
										16	32.06
										S	Sulfur
										17	35.453
										Cl	Chlorine
										18	39.948
										Ar	Argon
										29	63.546
										Cu	Copper
										30	65.38
										Zn	Zinc
										31	69.723
										Ga	Gallium
										32	72.64
										Ge	Germanium
										33	74.9216
										As	Arsenic
										34	77.94
										Se	Selenium
										35	78.96
										Br	Bromine
										36	85.36
										Kr	Krypton
										47	107.8682
										Ag	Silver
										48	112.411
										Cd	Cadmium
										49	114.818
										In	Indium
										50	118.710
										Sn	Tin
										51	121.757
										Sb	Antimony
										52	127.6
										Te	Tellurium
										53	126.905
										I	Iodine
										54	131.29
										Xe	Xenon
										79	196.967
										Au	Gold
										80	200.59
										Hg	Mercury
										81	204.387
										Tl	Thallium
										82	207.19
										Pb	Lead
										83	208.98
										Bi	Bismuth
										84	208.98
										Po	Polonium
										85	210
										At	Astatine
										86	222
										Rn	Radon
										65	158.925
										Tb	Terbium
										66	162.50
										Dy	Dysprosium
										67	164.930
										Ho	Holmium
										68	167.257
										Er	Erbium
										69	168.930
										Tm	Thulium
										70	173.054
										Yb	Ytterbium
										71	174.967
										Lu	Lutetium
										97	158.925
										Bk	Berkelium
										98	158.925
										Cf	Californium
										99	158.925
										Es	Einsteinium
										100	158.925
										Fm	Fermium
										101	158.925
										Md	Mendelevium
										102	158.925
										No	Nobelium
										103	158.925
										Lw	Livermorium

---

**Greek alphabet**


---

<b>A</b> $\alpha$	<b>Alpha</b>	<b>N</b> $\nu$	<b>Nu</b>
<b>B</b> $\beta$	<b>Beta</b>	<b>Ξ</b> $\xi$	<b>Xi</b>
<b>Γ</b> $\gamma$	<b>Gamma</b>	<b>Ο</b> $\omicron$	<b>Omicron</b>
<b>Δ</b> $\delta$	<b>Delta</b>	<b>Π</b> $\pi$	<b>Pi</b>
<b>E</b> $\epsilon$	<b>Epsilon</b>	<b>Ρ</b> $\rho$	<b>Rho</b>
<b>Z</b> $\zeta$	<b>Zeta</b>	<b>Σ</b> $\sigma$	<b>Sigma</b>
<b>H</b> $\eta$	<b>Eta</b>	<b>Τ</b> $\tau$	<b>Tau</b>
<b>Θ</b> $\theta$	<b>Theta</b>	<b>Υ</b> $\upsilon$	<b>Upsilon</b>
<b>I</b> $\iota$	<b>Iota</b>	<b>Φ</b> $\phi$	<b>Phi</b>
<b>K</b> $\kappa$	<b>Kappa</b>	<b>Χ</b> $\chi$	<b>Chi</b>
<b>Λ</b> $\lambda$	<b>Lambda</b>	<b>Ψ</b> $\psi$	<b>Psi</b>
<b>M</b> $\mu$	<b>Mu</b>	<b>Ω</b> $\omega$	<b>Omega</b>

---

**Bibliography**

Reviews of Particle Properties, *Rev. Mod. Phys.*, **52**, 1980.

*Handbook of Chemistry and Physics*, Weast, R. C., ed., CRC Press, Inc.

*Landolt-Börnstein: Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik, und Technik*, Springer-Verlag.

*International Critical Tables of Numerical Data, Physics, Chemistry, and Technology*, McGraw-Hill Book Company.

---

# Chapter 2

## *Astronomy and astrophysics*

The Solar System	25
<i>The Sun</i>	25
<i>Solar System elemental abundances</i>	30
<i>The planets (physical elements)</i>	31
<i>The planets (orbital elements)</i>	32
<i>Natural satellites in the Solar System</i>	33
<i>Short period comets</i>	36
<i>Principal meteor streams</i>	37
Stars	38
<i>Star charts</i>	38
<i>Constellations</i>	40
<i>The brightest stars</i>	44
<i>The 100 visually brightest stars</i>	45
<i>Stars within 5 pc</i>	50
<i>Nearest stars</i>	52
<i>Stars of large proper motion</i>	53
<i>The 21 fastest pulsars</i>	54
<i>Pulsars</i>	56
<i>Binary radio pulsars</i>	58
<i>OB associations</i>	59
<i>Orbital elements of binary stars</i>	61
<i>Classification of variable stars</i>	62
<i>Galactic supernova remnants</i>	64
<i>Henry Draper spectral classification</i>	64
<i>Spectral type and luminosity class</i>	65
<i>Hertzsprung–Russell diagram</i>	66
<i>Infrared and visible spectral features</i>	67
<i>The main sequence</i>	68



- [\*read online The 1% and the Rest of Us: A Political Economy of Dominant Ownership.pdf\*](#)
- [download online How to Be an Adult in Relationships: The Five Keys to Mindful Loving](#)
- [read online American Cultural Patterns: A Cross-Cultural Perspective](#)
- [\*\*download online Ms. American Pie: Buttery Good Pie Recipes and Bold Tales from the American Gothic House\*\*](#)
  
- <http://fortune-touko.com/library/Judas--The-Most-Hated-Name-in-History.pdf>
- <http://fortune-touko.com/library/How-to-Be-an-Adult-in-Relationships--The-Five-Keys-to-Mindful-Loving.pdf>
- <http://www.celebritychat.in/?ebooks/Ruling-the-Void--The-Hollowing-Out-of-Western-Democracy.pdf>
- <http://patrickvincitore.com/?ebooks/Ms--American-Pie--Buttery-Good-Pie-Recipes-and-Bold-Tales-from-the-American-Gothic-House.pdf>