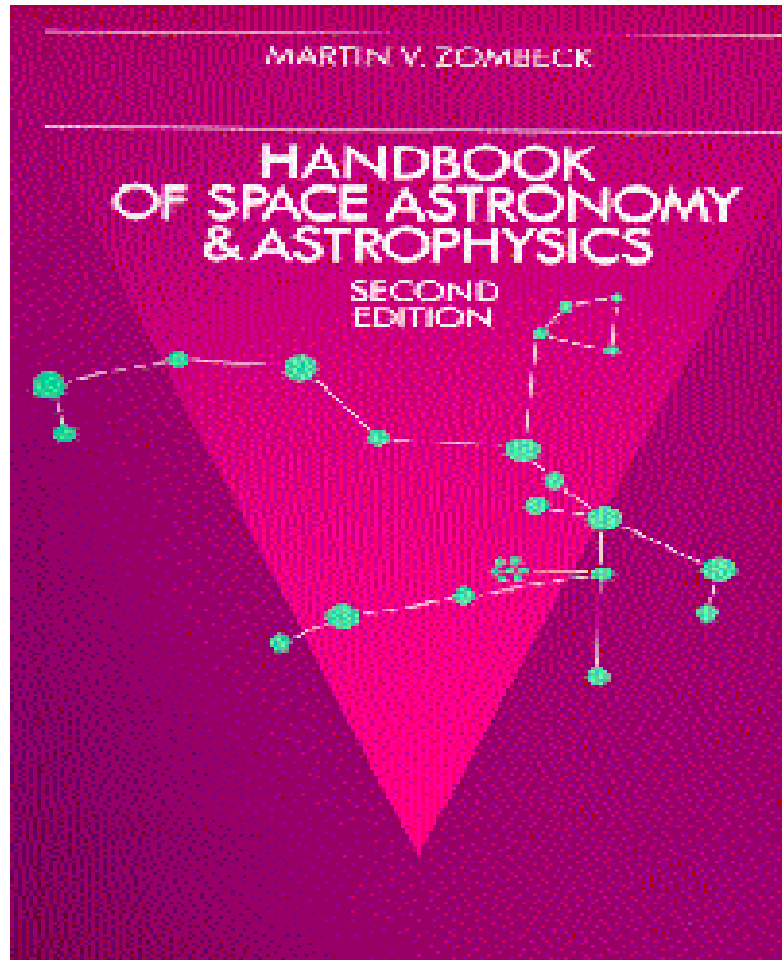


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Chapter 1

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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)
GENERAL CONSTANTS				
UNIVERSAL CONSTANTS				
speed of light in vacuum	c	299 792 458	m s^{-1}	(exact)
permeability of vacuum	μ_0	$4\pi \times 10^{-7}$ $= 12.566 370 614$	N A^{-2}	(exact)
permittivity of vacuum	ϵ_0	$1/360\pi^2$ $= 8.854 187 817 \dots$	$10^{-12} \text{ F m}^{-1}$	(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} J s	0.60
in electron volts, h/eV	h	4.135 669 2(12)	10^{-15} eV s	0.30
in electron volts, h/eV	h	1.054 572 66(63)	10^{-36} J s	0.60
Planck mass, $(hc/G)^{1/2}$	m_P	6.582 122 0(20)	10^{-8} kg	0.30
Planck length, $(hc/G)^{1/2}$	l_P	2.176 71(14)	10^{-35} m	64
Planck time, l_P/c $(hG/c^3)^{1/2}$	t_P	1.616 46(10)	10^{-43} s	64
		5.390 56(34)	10^{-44} s	64
ELECTROMAGNETIC CONSTANTS				
elementary charge	e	1.602 177 33(49)	10^{-19} C	0.30
magnetic flux quantum, $h/2e$	Φ_0	2.417 988 36(72)	10^{-14} Wb	0.30
Josephson frequency voltage ratio	$2e/h$	2.067 834 6(16)	10^{-15} Vb	0.30
quantized Hall conductance	e^2/h	4.835 976 7(14)	$10^{14} \text{ Hz V}^{-1}$	0.30
quantized Hall resistance, $h/e^2 = 3/8g_0 r$	R_H	3.874 046 14(17)	10^{-3} S	0.145
		25 812.805 6(12)	Ω	0.145

Bohr magneton, $eh/2m_e$, in electron volts, $\mu_B/ e $ in hertz, μ_B/h in wavenumbers, μ_B/hc in kelvins, μ_B/k	μ_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)	$10^{-24} \text{ J T}^{-1}$ $10^{-5} \text{ eV T}^{-1}$ $10^{10} \text{ Hz T}^{-1}$ $\text{m}^{-1} \text{ T}^{-1}$ 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, μ_N/h in wavenumbers, μ_N/hc in kelvins, μ_N/k	μ_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)	$10^{-27} \text{ J T}^{-1}$ $10^{-8} \text{ eV T}^{-1}$ MHz T^{-1} $10^{-2} \text{ m}^{-1} \text{ T}^{-1}$ 10^{-4} K T^{-1}	0.34 0.089 0.30 0.30 8.5
ATOMIC CONSTANTS				
ATOM				
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	α α^{-1} R_∞ 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} m^{-1} 10^{15} Hz 10^{-18} J eV 10^{10} m 10^{-18} J 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
ELECTRON				
electron mass in electron volts, $m_e c^2/ e $ electron muon mass ratio electron proton mass ratio electron deuteron mass ratio electron α -particle mass ratio	m_e m_e/m_μ m_e/m_p m_e/m_d m_e/m_α	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} kg 10^{-4} u 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, $h/m_e c$	λ_C	2.426 310 56(22)	10^{-12} m	0.089
$\lambda_C/2\pi = \alpha/4\pi R_\infty$	λ_C	1.861 593 23(35)	10^{-11} m	0.089
classical electron radius, $\alpha^2 a_0$	r_e	2.817 940 92(38)	10^{-17} m	0.13
Thomson cross-section, $(8\pi/3)r_e^2$	σ_T	0.665 246 16(18)	10^{-28} m^2	0.27
electron magnetic moment	μ_B	928.477 01(51)	10^{-26} JT^{-1}	0.34
in Bohr magnetons	μ_B/μ_N	1.001 159 652 193(10)		1×10^{-6}
in nuclear magnetons	μ_B/μ_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)		1×10^{-6}
electron muon magnetic moment ratio	μ_e/μ_μ	206.766 967(30)		0.15
electron proton magnetic moment ratio	μ_e/μ_p	658.210 658 1(66)		0.010
M C U N				
muon mass	m_μ	1.883 532 7(11)	10^{-26} kg	0.61
in electron volts, $m_\mu c^2/(e)$		0.113 428 913(17)	μ	0.15
muon electron mass ratio	m_μ/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	μ_μ	1.134 289 13(17)	$10^{-24} \text{ kg mol}^{-1}$	0.15
in Bohr magnetons	μ_μ/μ_B	4.490 451 4(15)	10^{-26} JT^{-1}	0.33
in nuclear magnetons	μ_μ/μ_N	4.841 970 97(71)	10^{-25}	0.15
muon magnetic moment anomaly, $[\alpha_\mu/(e\hbar/2m_\mu)] - 1$	a_μ	8.890 598 1(13)	10^{-3}	0.15
muon g-factor, $2(1 + a_\mu)$	g_μ	1.165 923 0(84)		7.2
muon proton magnetic moment ratio	μ_μ/μ_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_μ	1836.152 70(17)		0.020
proton specific charge	e/m_p	6.880 244 4(13)	10^7 C kg ⁻¹	0.15
proton molar mass	$M(p), M_p$	9.576 830 9(39)	10^{-2} kg mol ⁻¹	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	μ_p	2.103 069 37(19)	10^{-26} J T ⁻¹	0.089
in Bohr magnetons	μ_p/μ_B	1.410 607 6(47)	10^{-2}	0.34
in nuclear magnetons	μ_p/μ_N	1.521 032 20(15)		0.010
diamagnetic shielding correction for protons in pure water, spherical sample, 25 °C, $1 - \mu_p^2/\mu_0^2$	σ_{H_2O}	2.792 847 386(63)		0.023
shielded proton moment (H ₂ O, sph., 25 °C)	μ_p'	25.689(15)	10^{-26} J T ⁻¹	0.34
in Bohr magnetons	μ_p'/μ_B	1.410 571 38(47)	10^{-2}	0.011
in nuclear magnetons	μ_p'/μ_N	1.520 993 129(17)		0.023
proton gyromagnetic ratio	γ_p	2.792 772 642(64)	10^4 s ⁻¹ T ⁻¹	0.30
uncorrected (H ₂ O, sph., 25 °C)	$\gamma_p/2\pi$	26 752.2128(61)	MHz T ⁻¹	0.30
	$\tilde{\gamma}_p/2\pi$	42.577 469(13)	10^4 s ⁻¹ T ⁻¹	0.30
	$\tilde{\gamma}_p'/2\pi$	26 751.5255(61)	MHz T ⁻¹	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 ⁻¹	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 ^(a) in Bohr magnetons	μ_n	0.966 237 07(40)	$10^{-26} \text{ J T}^{-1}$	0.41
in nuclear magnetons	μ_n/μ_N	1.041 875 63(25)	10^{-3}	0.24
in nuclear magnetons	μ_n/μ_K	1.913 042 75(45)		0.24
neutron–electron magnetic moment ratio	μ_n/μ_e	1.040 668 82(25)	10^{-2}	0.24
neutron–proton magnetic moment ratio	μ_n/μ_p	0.684 979 34(16)		0.24
DEUTERON				
deuteron mass	m_d	3.343 586 0(20)	10^{-27} 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)	$10^{-3} \text{ kg mol}^{-1}$	0.012
deuteron molar mass	μ_d	0.433 073 75(15)	$10^{-26} \text{ J T}^{-1}$	0.34
deuteron magnetic moment ^(a) in Bohr magnetons	μ_d/μ_B	0.466 975 447 94(1)	10^{-3}	0.019
in nuclear magnetons	μ_d/μ_N	0.857 438 250(24)		0.028
deuteron electron magnetic moment ratio	μ_d/μ_e	0.466 434 546 0(9.1)	10^{-2}	0.019
deuteron–proton magnetic moment ratio	μ_d/μ_p	0.387 012 203 5(5.1)		0.017
PHYSICO-CHEMICAL CONSTANTS				
Avogadro constant	N_A, L	6.022 136 7(36)	10^{23} 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} 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)	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)	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 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		69.503 87(59)	$\text{m}^3 \cdot \text{K}^{-1}$	8.4
$T = 273.15 \text{ K}$, $p = 101 325 \text{ Pa}$	V_m	22.414 10(19)	L mol^{-1}	8.4
Loschmidt constant, N_A/V_m	ρ_0	2.686 763(23)	10^{25} m^{-3}	8.5
$T = 273.15 \text{ K}$, $p = 100 \text{ kPa}$	V_m	22.7118(19)	L mol^{-1}	8.4
Sackur-Tetrode constant (absolute entropy constant), $\frac{5}{2}R + \ln\{2\pi m_0 k_B^3 / 3h^3 p_0 T_0\}$	S_0/R	1.151 693(21)		18
$T_0 = 1 \text{ K}$, $p_0 = 100 \text{ kPa}$	p_0	1.164 856(21)		18
Stefan Boltzmann constant, $(\pi^5/60)k_B^4/c^2$	σ	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} W m^2	0.60
second radiation constant, hc/k_B	c_2	0.014 387 69(12)	m K	8.4
Wien displacement law constant,	b	2.897 756(24)	10^{-3} m K	8.4
$b = \lambda_{\text{max}} T = c_2/4.965 114 23 \dots$				

¹⁰⁾ 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.

¹¹⁾ 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)
MAINTAINED ELECTRICAL UNITS				
BIPM ⁽⁶⁾ maintained ohm, Ω_{Cu-Bi}	Ω_{BIPM}	$1 - 1.563(50) \times 10^{-6}$ $= 0.999 998 437(50)$	Ω	0.050
$\Omega_{\text{BIPM}} = \Omega_{Cu-Bi}$ (1 J _{ESU} '085)				
drift rate of Ω_{Cu-Bi}	$\frac{d\Omega_{Cu-Bi}}{dt}$	0.0566(15)	$\mu\Omega/a$	—
BIPM maintained volt, V_{70-Bi}	V_{70-Bi}	$1 - 7.59(30) \times 10^{-6}$ $- 0.999 992 41(30)$	V	0.30
BIPM maintained ampere, $A_{BIPM} = V_{70-Bi}/\Omega_{Cu-Bi}$	A_{BIPM}	$1 - 6.03(30) \times 10^{-6}$ $= 0.999 993 97(30)$	A	0.30
X-RAY STANDARDS				
Cu x-unit: $\lambda(CuK\alpha_1) \equiv 1537.40(10)$ XU	$\lambda(CuK\alpha_1)$	1.002 077 89(70)	$10^{-12} m$	0.70
Mo x-unit: $\lambda(MoK\alpha_1) \equiv 707.831(10)$ XU	$\lambda(MoK\alpha_1)$	1.002 099 38(45)	$10^{-12} m$	0.45
\AA^* : $\lambda(WK\alpha_1) \equiv 0.209 100 \text{\AA}^*$	\AA^*	1.000 014 51(92)	$10^{-10} m$	0.92

lattice spacing of Si (in vacuum, 22.5 °C) ^(a)	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 ³ mol ⁻¹	0.74

^(a) BIPM: Bureau International des Poids et Mesures.

^(b) The lattice spacing of single-crystal Si can vary by parts in 10⁷ 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.

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Fundamental physical constants (e.g.s.)

Speed of light in vacuum	$c = 2.997\,924\,58 \times 10^{10} \text{ cm s}^{-1}$
Gravitational constant	$G = 6.672\,59 \times 10^{-8} \text{ dyn cm}^2 \text{ g}^{-2}$
Planck's constant	$h = 6.626\,075\,5 \times 10^{-27} \text{ erg s}$
Electron charge	$e = 4.803\,206\,8 \times 10^{-10} \text{ esu}$
Mass of electron	$m_e = 9.109\,389\,7 \times 10^{-28} \text{ g}$
Mass of proton	$m_p = 1.672\,623\,1 \times 10^{-24} \text{ g}$
Mass of neutron	$m_n = 1.674\,928\,6 \times 10^{-24} \text{ g}$
Atomic mass unit (amu)	$m_u = 1.660\,540\,2 \times 10^{-24} \text{ g}$
Proton-electron mass ratio	$m_p/m_e = 1\,836.152\,701$
Fine structure constant	$hc/2\pi e^2 = 1/\alpha = 137.035\,989\,5$
Classical electron radius	$e^2/m_e c^2 = r_e = 2.817\,940\,92 \times 10^{-13} \text{ cm}$
Bohr radius	$h^2/4\pi^2 m_e e^2 = a_0 = 0.529\,177\,249 \times 10^{-8} \text{ cm}$
Electron Compton wavelength	$h/m_e c = \lambda_c = 2.426\,310\,58 \times 10^{-10} \text{ cm}$
Rydberg constant	$2\pi^2 m_e e^4 / hc^3 = R_\infty = 109\,737\,315.34 \text{ cm}^{-1}$
Boltzmann constant	$k = 1.380\,658 \times 10^{-16} \text{ erg K}^{-1}$
Stefan-Boltzmann constant	$\sigma = 2\pi^5 k^4 / 15 h^3 c^2$ $= 5.670\,51 \times 10^{-5} \text{ erg cm}^{-2} \text{ K}^{-4} \text{ s}^{-1}$
Thomson cross-section	$8\pi r_e^2/3 = \sigma_T = 0.665\,246\,16 \times 10^{-24} \text{ cm}^2$
Bohr magneton	$eh/4\pi m_e = \mu_B = 9.274\,015\,4 \times 10^{-21} \text{ gauss cm}^2$

(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	$J_2 = 0.001\,082\,63$
Gravity at Earth's surface (mean)	$g_e = 980.7 \text{ cm s}^{-2}$
Ratio of mass of Moon to that of Earth	$\mu = 0.012\,300\,02$
Lunar distance (mean)	$3.844\,01 \times 10^{10} \text{ cm}$
Astronomical unit	$\text{AU} = 1.495\,978\,70 \times 10^{13} \text{ cm}$
Mass of the Earth	$M_e = 5.976 \times 10^{27} \text{ g}$
Solar parallax	$\pi_\odot = 8''.794\,148$
Tropical year (1900.0)	365.242 days $3.1557 \times 10^7 \text{ ephemeris seconds}$
Ephemeris day	86 400 ephemeris seconds
Constant of aberration (2000.0)	$K = 20''.495\,52$
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	$\Omega = 7.292\,115 \times 10^{-5} \text{ rad s}^{-1}$
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 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 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 $3.7 \times 10^{10} \text{ disintegrations s}^{-1}$	
1 nautical mile = 1852 m	
1 statute mile = 1609.344 m	
intensity ($\text{erg cm}^{-2} \text{ s}^{-1} \text{ Hz}^{-1}$) = $3.33 \times 10^{-16} \lambda^2(\text{\AA}) \text{ intensity} (\text{erg cm}^{-2} \text{ s}^{-1} \text{ \AA}^{-1})$	
1 barn = 10^{-24} 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
LENGTH				
	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	$1.609\ 344\text{E}+03$	meter (SI)
	1	astron. unit (AU)	$1.495\ 981\text{E}+11$	meter (SI)
	1	solar radius	$6.959\ 901\text{E}+08$	meter (SI)
	1	centimeter (cgs)	$3.240\ 781\text{E}-19$	parsec
	1	centimeter (cgs)	$6.684\ 561\text{E}-14$	astron. unit (AU)
	1	meter (SI)	$3.240\ 781\text{E}-17$	parsec
	1	meter (SI)	$6.684\ 541\text{E}-12$	astron. unit (AU)
	1	inch (Eng)	$2.540\ 001\text{E}-02$	meter (SI)
MASS				
	1	kilogram (SI)	$1.000\ 001\text{E}-03$	gram (cgs)
	1	at. mass unit (amu)	$1.660\ 541\text{E}-24$	gram (cgs)
	1	at. mass unit (amu)	$1.660\ 541\text{E}-27$	kilogram (SI)
	1	solar mass	$1.989\ 101\text{E}+33$	gram (cgs)
	1	solar mass	$1.989\ 101\text{E}-30$	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.)
ENERGY		
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 ² = 9.314 93E - 08	electron volt
1	gm (cgs) x c ² = 5.609 59E + 32	electron volt
1	calorie = 4.184 00E + 00	joule (SI)
FORCE		
1	newton (SI) = 1.000 00E + 05	dyne (cgs)
1	dyne (cgs) = 1.000 00E - 05	newton (SI)
PRESSURE		
1	pascal (SI) = 1.000 00E - 00	newton m ⁻² (SI)
1	bar = 1.000 00E - 06	Dyne cm ⁻² (cgs)
1	bar = 9.869 23E - 01	atmosphere
1	torr = 1.333 22E - 03	bar
POWER		
1	watt (SI) = 1.000 00E + 07	erg s ⁻¹ (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
TIME				
	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
TEMPERATURE				
	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
ELECTRICITY AND MAGNETISM				
Charge	1	coulomb = 2.997 92E + 09		statcoulomb
Charge density	1	coulomb m ⁻³ = 2.997 92E + 03		statcoul cm ⁻³
Current	1	ampere (coul s ⁻¹) = 2.997 92E + 09		statampere
Current density	1	ampere m ⁻² = 2.997 92E + 05		statamp cm ⁻²
Electric field	1	volt m ⁻¹ = 3.335 65E - 05		statvolt cm ⁻¹
Potential	1	volt = 3.335 65E - 03		statvolt

Resistance	ohm = 1.112 65E - 12	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 m^{-1} = 8.987 52E - 09	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 m^{-1} = 1.256 64E - 02	oersted
Inductance	henry = 1.112 65E - 12	$\text{s}^2 \text{ohm}^{-1}$
MISCELLANEOUS		
Radio-activity	curie (SI) = 3.700 00E - 10	disinteg. 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 = 1.219 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 ² = 3.2828 × 10 ⁻⁴ deg ²
$\ln 10 = 2.302\,585\,1$	$= 1.1818 \times 10^7$ arcmin ²
$\log_{10} e = 0.434\,294\,5$	$= 4.2545 \times 10^{10}$ arcsec ²
$(2\pi)^{1/2} = 2.506\,628$	degree = 0.017 453 3 rad
$\pi^2 = 9.869\,604$	arcmin = 2.908 88 × 10 ⁻⁴ rad
$2^{10} = 1024$	arcsec = 4.848 137 × 10 ⁻⁵ rad
$e^{-2} = 0.367\,879\,4$	deg ² = 3.0462 × 10 ⁻¹ steradian
$\Gamma(n+1) = n!$, integer n	arcmin ² = 8.4617 × 10 ⁻⁸ steradian
$\Gamma(1/2) = \pi^{-1/2}$	arcsec ² = 2.3504 × 10 ⁻¹¹ 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 ^(a) (s)
Photon	0	0	1	0	stable
π -meson	+1, -1	0.149 84	1	0	2.60×10^{-8}
	0	0.144 90	0	0	0.83×10^{-16}
Neutrino	0	$< 10^{-6}$	1/2	~ 0	stable
Electron, positron	-1, +1	0.000 548 6	1/2	$1.001 160 \mu_B^{(b)}$	stable
μ -meson	-1, +1	0.1134	1/2	$0.004 842 \mu_B$	2.20×10^{-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

^(a) half-life = mean life $\times \ln 2$

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

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

(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)
LEPTONS				
e		$\frac{1}{2}$	0.511 003	Stable
μ		$\frac{1}{2}$	105.6594	$2.197\ 14 \times 10^{-6}$
τ		$\frac{1}{2}$	1784	5×10^{-13}
NONSTRANGE BARYONS				
p	$\frac{1}{2}$	$\frac{1}{2}^-$	938.280	Stable
n	$\frac{1}{2}$	$\frac{1}{2}^-$	939.573	925
Δ	$\frac{3}{2}$	$\frac{3}{2}^-$	1232	6×10^{-24}
STRANGENESS = -1 BARYONS				
Λ	0	$\frac{1}{2}$	1115.60	2.63×10^{-10}
Σ^+	1	$\frac{1}{2}^-$	1189.36	8.00×10^{-11}
Σ^0	1	$\frac{1}{2}^-$	1192.46	6×10^{-20}
Σ^-	1	$\frac{1}{2}^-$	1197.34	1.48×10^{-10}
STRANGENESS = -2 BARYONS				
Ξ^0	$\frac{1}{2}$	$\frac{1}{2}^-$	1314.9	2.9×10^{-10}
Ξ^-	$\frac{1}{2}$	$\frac{1}{2}^-$	1321.3	1.64×10^{-10}
STRANGENESS = -3 BARYON				
Ω^-	0	$\frac{3}{2}^-$	1672.5	8.2×10^{-11}
NONSTRANGE CHARMED BARYON				
Λ_c^+	0	$\frac{1}{2}^-$	2282	1×10^{-13}
NONSTRANGE MESONS				
π^+	1	0^-	139.567	2.603×10^{-8}
π^0	1	0^-	134.963	8.3×10^{-17}
η	0	0^-	548.8	8×10^{-16}
ρ	1	1^-	769	4.3×10^{-24}
ω	0	1^-	782.6	6.6×10^{-23}
η'	0	0^-	957.6	2.4×10^{-21}
ϕ	0	1^-	1019.6	1.6×10^{-22}
J/Ψ	0	1^-	3096.9	1.0×10^{-20}
Υ		1	9456	1.6×10^{-20}
STRANGENESS = -1 MESONS				
K^+	$\frac{1}{2}$	0	493.67	1.237×10^{-8}
K^0, \bar{K}^0	$\frac{1}{2}$	0	497.7	$K_S^0: 8.92 \times 10^{-11}$ $K_L^0: 5.18 \times 10^{-9}$
CHARMED NONSTRANGE MESONS				
D	$\frac{1}{2}$	0^-	1869.4	9×10^{-12}
D^+, D^0	$\frac{1}{2}$	0^-	1864.7	5×10^{-13}
CHARMED STRANGE MESON				
F^+	0	0^-	2021	2×10^{-13}

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

Energy conversions

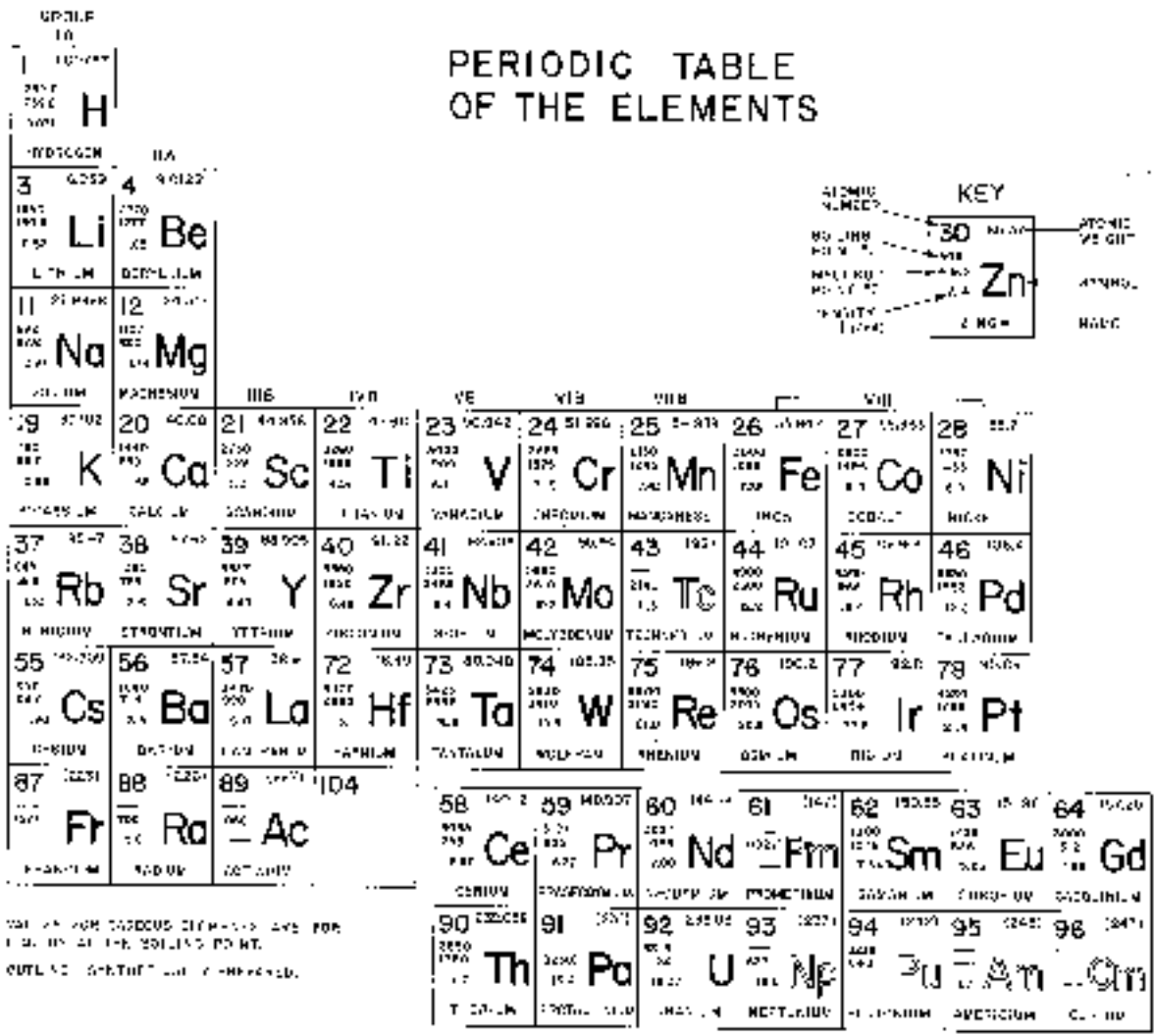
1 erg	= 1 dyne-centimeter = 10^{-7} joule
1 joule	= 1 newton-meter
1 foot-pound	= 1.356 joule
1 calorie	= 4.184 joule
1 Btu	= 1.055×10^3 joule
1 horsepower-hour	= 2.6845×10^6 joule
1 kilowatt-hour	= 3.6×10^6 joule = 3.413×10^3 Btu
1 MeV	= 1.6×10^{-13} joule
Energy of fission of 1 atom of ^{235}U	= 199 MeV = 3.2×10^{-11} joule
Energy equivalent of 1 ton of TNT	= 4.2×10^9 joule
Energy of fission of 1 kilogram of ^{235}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	= 9×10^{13} joule
High heat value of 1 ton of coal	= 26×10^6 Btu
High heat value of 1 cord of red oak	= 30×10^6 Btu
High heat value of 100 gallons of fuel oil	= 15×10^6 Btu
High heat value of 20 000 cu ft natural gas	= 20×10^6 Btu
US energy consumption	= 10^{20} joule yr^{-1} (proj. 1970–2000)
Earth's daily receipt of solar energy	= 1.49×10^{22} joule = 4.2×10^{12} Mwh
Earth's rotational energy	= 2.2×10^{29} joule
Earth's total heat content	= 3×10^{31} joule
1 D-cell flashlight battery	= 116 watt-s = 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	μ
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															
										5	10.81	6	12.011	7	14.0067	8	15.9994	9	18.9984	10	20.1803	Ne						
										B	SCANDIUM	C	CARBON	N	NITROGEN	O	OXYGEN	F	FLUORINE									
										13	26.9815	14	28.0856	15	30.9738	16	32.06	17	35.453	18	39.948	Ar						
										Al	GALLIUM	Si	SILICON	P	PHOSPHORUS	S	SULFUR	Cl	CHLORINE									
-B	-B											29	63.546	30	65.38	31	69.723	32	72.64	33	74.922	34	77.947	35	79.904	36	83.80	Kr
Cu	Zn	Ga	Ge	As	Se	Br	Kr																					
COBALT	ZINC	GALLIUM	GERMANIUM	ARSENIC	SELENIUM	BROMINE	KRYPTON																					
47	78.96	48	112.411	49	114.818	50	118.710	51	121.757	52	127.60	53	126.905	54	131.29	Xe												
Ag	Cd	In	Sn	Sb	Te	I	Xe																					
SILVER	CADMIUM	INDIUM	TIN	ANTIMONY	TELLURUM	IODINE	XENON																					
79	196.967	80	200.59	81	204.37	82	207.19	83	208.98	84	208.98	85	210	86	222	Rn												
Au	Hg	Tl	Pb	Bi	Po	At	Rn																					
GOLD	MERCURY	THALLIUM	LEAD	BISMUTH	POLONIUM	ASTATINE	RADON																					
65	158.925	66	162.50	67	164.930	68	167.259	69	168.930	70	173.054	71	174.967	Lu														
Tb	Dy	Ho	Er	Tm	Yb	Lu																						
TERBOLIUM	DYSPROSIUM	HOLEMIUM	ERBIUM	THULIUM	Ytterbium	LUTETIUM																						
97	247.077	98	243.061	99	244.063	100	244.063	101	244.063	102	244.063	103	244.063	Lw														
Bk	Cf	Es	Fm	Md	No	Lw																						
BERKELIUM	CALIFORNIA	EINSTEINIUM	FERMIUM	MEISSNERIUM	Nobelium	LAWRENCIUM																						

Greek alphabet

A α	Alpha	N ν	Nu
B β	Beta	Ξ ξ	Xi
Γ γ	Gamma	O \omicron	Omicron
Δ δ	Delta	Π π	Pi
E ϵ	Epsilon	Ρ ρ	Rho
Z ζ	Zeta	Σ σ	Sigma
H η	Eta	Τ τ	Tau
Θ θ	Theta	Υ υ	Upsilon
I ι	Iota	Φ ϕ	Phi
K κ	Kappa	Χ χ	Chi
Λ λ	Lambda	Ψ ψ	Psi
M μ	Mu	Ω ω	Omega

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Chapter 2

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