Fundamental Physical Constants and Conversion Factors

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1. INTRODUCTION

SI is the servant of man, not his master
P. Vigoureux [1971]

This section provides a summary of important units for geomagnetism and geoelectricty. In addition, a summary of conversion factors and fundamental units of relevance to earth and planetary science are presented for reference.

Despite the sentiment expressed above by Vigoureux, it still seems that plenty of us slave over SI units in geomagnetism. There is probably no other scientific discipline in which the topic of units generates so much endless discussion and confusion than in magnetism. Before the late 1970's, practically all the geophysical literature in geomagnetism and paleomagnetism used the Gaussian CGS system of units. The CGS system is a perfectly sound, internally consistent, system of units, but, like all systems of units and dimensions, is totally arbitrary. As the name implies, the cgs system is based on three base units: centimeter, gram, and second. All other units are derived from these three. The Gaussian cgs system is based on two earlier systems, the electrostatic units (esu) and electromagnetic units (emu). Electrostatic units were defined by Coulomb's law describing the force between two electrical charges. Similarly, electromagnetic units were defined by the force between two magnetic charges or two current-carrying wires. One consequence of this dichotomy is that the dimensions of electric charge and other related quantities are different in the esu and emu systems. The Gaussian system is a mixture of these two subsets and uses the emu system to describe magnetic quantities and the esu system to describe electrical quantities. As a result of combining the emu and esu system into the Gaussian system, the velocity of light in vacuum appears explicitly in some equations dealing with magnetic and electric effects. This resulted in a cumbersome set of units with "inconvenient" magnitudes for practical electrical units such as the volt, ohm, and ampere.

The Système International, or SI system of units, are now the recommended (and required!) units for scientific and commercial use, as decided by international committees and journal editors. The SI system, or MKSA, is also totally arbitrary and is based on four base units: meter, kilogram, second, and ampere. The introduction of the ampere as a base unit instead of a derived unit has some great advantages. Besides doing away with the emu and esu systems, the SI system incorporating ampere as a base unit also eliminates all those weird "ab" and "stat" emu and esu units, such as abampere and statcoulomb. The price we pay for this "unit-fication", however, becomes apparent for workers in magnetism. Suddenly factors of 4π disappear from, or reappear elsewhere in, formulae. Further, the permeability of free space (μ_0) and the permittivity of free space (ε_0), which were dimensionless, equal to unity, and often ignored in the cgs world, now take on dimensions and numerical values much different from unity. Likewise, the magnitudes of various magnetic parameters that we deal with every day in the laboratory have changed, some becoming much larger, others smaller, and all somewhat unfamiliar. This short section provides a brief review of the cgs and SI system of units in magnetism (also see 2,5-8).

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2. THE REALLY IMPORTANT MAGNETIC TERMS

Following Shive [7] and Payne [5], there are four fundamental magnetic quantities:

B= magnetic induction, or flux density
H= magnetic field strength, or magnetizing force
M= magnetization per unit volume
J= magnetic polarization, or magnetization

In the SI system, the relationship between B, H, M, and J is given by

$$B = \mu_0 H + J \tag{1}$$

$$B = \mu_0 (H + M) \tag{2}$$

$$J = \mu_0 M \tag{3}$$

where μ_0 is $4\pi x 10^{-7}$ Newton/Ampere^2 and is called the permeability of free space. In free space a magnetic field produces a magnetic induction given by $B=\mu_0 H$. If the space is filled by any magnetic material the magnetization will produce an additional magnetic induction given by $\mu_0 M$. The total induction is the sum of these two contributions and is given by equation (2). Equations (1) and (2) are usually associated respectively with the names of Kennelly and Sommerfeld and represent two alternative definitions of the magnetic moment of a current loop. By equation (1), the dimensions of B and J are the same and the appropriate unit is the Weber/m^2 or tesla. Similarly, by equation (2), the dimensions of H and M are the same and the appropriate unit is the ampere m^{-1}, or Am^{-1}. Equation (2) is the officially recognized SI convention. Another related quantity is the volume magnetic susceptibility (κ) and is defined as

$$\kappa = \frac{M}{H} = \frac{J}{\mu_0 H} \tag{4}$$

The volume magnetic susceptibility is dimensionless.

In the cgs system, the relationship between B, H, M, and J is given by

$$B = H + 4\pi J \tag{5}$$

$$J = M \tag{6}$$

The constant μ_0 is arbitrarily set to unity and is dimensionless. Therefore, the dimensions for B, H, J, and M are the same. The volume susceptibility is given by equation (4) and is also dimensionless. However, just because the dimensions of these quantities are the same, there is no reason to have the same names for the units. The name for B is gauss (G), for H is oersted (Oe), and for M and J is emu/cm^3. Often H and M are both given in gauss and no distinction is made between J and M. Since in free space B=H (in cgs), gauss is frequently used to express the magnitude of H. Yet this conceals a subtle difference between M (and H) and the induction J (and B), or flux density, it produces. By equation (5), one emu/cm^3 unit of magnetization will produce a magnetic induction B of $4\pi J$ gauss. The "correct" procedure would be to assign M or J units of emu/cm^3, and the quantity $4\pi J$ units of gauss. This is rarely done in the geophysical literature, but is common in engineering and physics.

3. CONVERSION ADVENTURES

The conversion factors between B, H, M and J in SI and cgs are as follows:

B: 1 T = 10^4 G
H: 1 Am^{-1} = $4\pi x 10^{-3}$ Oe
M: 1 Am^{-1} = 10^{-3} emu cm^{-3}
J: 1 T = $10^4/4\pi$ emu cm^{-3}

Right away we see a problem with converting emu cm^{-3} to the appropriate SI unit. Do we use the conversion for M or J? Although B and H, and, J and M, are used interchangeably in CGS system, we need to be more precise when converting to SI. For example, the earth's magnetic field is approximately 0.5 G, or 0.5 Oe. However, in SI

0.5 G = $5x10^{-4}$ T or 50 μT
0.5 Oe = 39.8 Am^{-1}

It is much easier to convert gauss to tesla (move the decimal point 4 places) than to convert oersted to Am^{-1}. So it is not too surprising that the current practice used by geophysicists is to report both B and H in free space (ie., in the absence of magnetized material, M=0) in tesla. We have not decided suddenly that the B field is more fundamental than the H field just that it is more convenient to use the units of B. When we now talk about an alternating "magnetic field" or some other H field of say 10 millitesla (mT), we really mean an induction of $\mu_0 H$=10 mT. However, this is rarely noted. The corresponding procedure for J (and M) in cgs is to convert emu cm^{-3} to Am^{-1} by moving the decimal three places and call the result the magnetization per unit volume, magnetization, or the intensity of magnetization.

To summarize briefly, when using cgs units, we usually deal with the magnetization J and the magnetic field H. When we convert to SI units, we use the magnetic moment

TABLE 1. Conversion factors for Magnetic Quantities

Magnetic Term	Symbol	SI Unit	CGS Unit	Conversion Factor
Magnetic induction	B	tesla (T)	gauss (G)	1 T = 10^4 G
Magnetic field	H	A m^{-1}	oersted (Oe)	1 A m^{-1} = 4π x 10^{-3} Oe
Magnetization	M	A m^{-1}	emu cm^{-3}	1 A m^{-1} = 10^{-3} emu cm^{-3}
Magnetic polarization	J	T	G	1 T = $10^4/4\pi$ emu cm^{-3}
Magnetic moment	m	A m^2	emu = G cm^3	1 A m^2 = 10^3 emu
Magnetic moment per unit mass	σ	A m^2 kg^{-1}	emu g^{-1}	1 A m^2 kg^{-1} = 1 emu g^{-1}
Volume magnetic susceptibility (κ=M/H)	κ	dimensionless	dimensionless	1(SI) = $1/4\pi$ (cgs)
Mass magnetic susceptibility ($\chi=\kappa/\rho$)	χ	m^3 kg^{-1}	emu Oe^{-1} g^{-1}	1 m^3 kg^{-1} = $10^3/4\pi$ emu Oe^{-1} g^{-1}
Molar magnetic susceptibility ($\chi_m=\chi M^*$)	χ_m	m^3 mol^{-1}	emu Oe^{-1} g^{-1} mol^{-1}	1 m^3 mol^{-1} = $10^6/4\pi$ emu $Oe^{-1}g^{-1}$ mol^{-1}
Magnetic permeability (μ=B/H)	μ	H m^{-1}	G Oe^{-1}	1 H m^{-1} = $10^7/4\pi$ G Oe^{-1}
Magnetic flux	Φ	Weber (Wb)	maxwell (Mx)	1 Wb = 10^8 Mx
Magnetic scalar potential; Magnetomotive force	ϕ	A	gilbert	1 A = $4\pi/10$ gilbert
Magnetic vector potential	A	Wb m^{-1}	emu = G cm	1 Wb m^{-1} = 10^6 emu
Magnetic pole strength	p	A m	emu = G cm^2	1 A m = 10 emu
Demagnetizing factor	N	dimensionless	dimensionless	1(SI) = 4π (cgs)
Magnetostriction constant	λ	dimensionless	dimensionless	1(SI) = 1(cgs)
Anisotropy constant Magnetostatic energy Energy product	K, K_1, K_u E_m $(BH)_{max}$	J m^{-3}	erg cm^{-3}	1 J m^{-3} = 10 erg cm^{-3}

A=ampere; H=Henry=Newton/Ampere; M^*=molecular weight; Tesla=Weber/m^2; ρ=density (1 kg/m^3=10^3 g/cm^3). Volume magnetic susceptibility in cgs units is sometimes given as emu cm^{-3} Oe^{-1} or G/Oe, both are dimensionless. Mass magnetic susceptibility in cgs units is sometimes given as emu g^{-1}, emu g^{-1} oe^{-1}, emu $g^{-1}G^{-1}$, G cm^3 g^{-1}, or cm^3 g^{-1}. The csg unit gamma $\gamma = 10^{-5}$ G = 10^{-9} T = 1 nanotesla (nT). The SI units are based on the Sommerfeld convention which gives the unit of magnetic moment as A m^2. The Kennelly convention gives the unit of magnetic moment as Wb m.

per unit volume, or simply the magnetization M and the magnetic induction B. As shown by Shive [7], when we convert to SI, J (gauss) and H (Oe) are first converted to M (emu/cm^3) and B (gauss) in cgs. Then we use the SI conversion scheme to convert M and B in cgs to their corresponding SI units of A/m and tesla. For example, to convert a magnetization of 10^{-3}G and a magnetic field of 100 oe from cgs to SI, we do the following:

TABLE 2. Conversion Factors for Electrical Quantities

Quantity	Symbol	SI Unit	CGS emu unit	CGS esu unit
Electric Charge	q	1 Coulomb (C)	0.1 abcoulomb	$0.1c$ statcoulomb
Current	I	1 Ampere (A)	0.1 abampere	$0.1c$ statampere
Electric Potential(emf)	V	1 volt (V)	10^8 abvolt	10^8c^{-1} statvolt
Resistance	R	1 ohm (Ω)	10^9 cm s^{-1}	10^9c^{-2} s cm^{-1}
Capacitance	C	1 farad (F)	10^{-9} s^2 cm^{-1}	$10^{-9}c^2$ cm
Inductance	L	1 Henry (H)	10^9 cm	10^9c^{-2} s^2 cm^{-1}
Conductance	G	1 siemen (S)	10^{-9} cm^{-1} s	$10^{-9}c^{-2}$ cm s^{-1}
Charge density	ρ_e	1 C m^{-3}	10^{-7} abcoul cm^{-3}	$10^{-7}c$ statcoul cm^{-3}
Current density	J_e	1 A m^{-2}	10^{-5} abamp cm^{-2}	$10^{-5}c$ statamp cm^{-2}
Electric Field	E	1 V m^{-1}	10^6 abvolt cm^{-1}	10^6c^{-1} statvolt cm^{-1}
Displacement vector	D	1 C m^{-2}	$4\pi x10^{-5}$ abcoul cm^{-2}	$4\pi x10^{-5}c$ statcoul cm^{-2}
Electric Polarization	P	1 C m^{-2}	10^{-5} abcoul cm^{-2}	$10^{-5}c$ statcoul cm^{-2}
Electrical conductivity	σ	1 S m^{-1}	10^{-11} cm^{-2} s	$10^{-11}c^2$ s^{-1}
Electrical Resistivity	ρ	1 Ω m	10^{11} cm^2 s^{-1}	$10^{11}c^{-2}$ s
Electric permittivity	ε	1 F m^{-1}	10^{-11} cm^{-2} s^2	$10^{-11}c^2$ esu

The table is arranged so that one SI unit equals the corresponding number of units in emu and esu. Quantities in each row, therefore, stands for the identical amount expressed in different units. The symbol c stands for the magnitude of the speed of light in vacuo expressed in cm/sec (=2.99792458x10^{10}). For example, 1 coulomb = $0.1c$ statcoulomb ≈ 3x10^9 statcoulomb. The Gaussian units for electrical quantities consist mostly of the es units in the last column.

J(cgs) = 10^{-3} G = M(cgs) = 10^{-3} emu cm^{-3}
= M(SI) = 1 Am^{-1}

H(cgs) = 100 Oe = B(cgs) = 100 G = B(SI) = 10 mT

This is the official conversion scheme recommended by the International Association of Geomagnetism and Aeronomy (IAGA) in 1973; unfortunately, the world outside geomagnetism uses a different convention. In most physics and engineering research papers that use SI units, a direct conversion using the Sommerfeld convention [equation (2)] is employed. In this case, the magnetizing field and magnetization are given in Am^{-1}. For example, a magnetic field of 100 Oe (CGS) would be given as 8000 Am^{-1} (SI) in a physics journal, but as 10 mT (SI) in a geophysics journal.

Various parameters and conversion factors are presented in the following tables. Tables 1 and 2 summarizes conversion factors for magnetic and electrical units, respectively. An extensive list of fundamental equations in electromagnetism in both SI and CGS is given by Payne [6] and the errata published later [7]. In Tables 3 to 6, conversion factors dealing with pressure, energy, spectroscopy units and fundamental physical constants are summarized.

TABLE 3. Conversion Factors for Pressure Units

	atm	bar	dyne cm^{-2}	kg m^{-2}	lb in^{-2} psi	Pascal Pa
1 atm=	1	1.01325	1.01325 x10^{6}	1.033227 x10^{4}	14.695595	1.01325 x10^{5}
1 bar=	9.86923 x10^{-1}	1	10^{6}	1.0197 x10^{4}	14.504	10^{5}
1 dyne cm^{-2}=	9.86923 x10^{-7}	10^{-6}	1	1.0197 x10^{-2}	1.4504 x10^{-5}	10^{-1}
1 kg m^{-2}=	9.678 x10^{-5}	9.8067 x10^{-5}	98.067	1	1.423 x10^{-3}	9.8067
1 lb in^{-2}=	0.068046	6.8948 x10^{-2}	6.8948 x10^{4}	7.0306 x10^{2}	1	6.8948 x10^{3}
1 Pascal=	9.869 x10^{-6}	10^{-5}	10	1.019 x10^{-1}	1.450 x10^{-4}	1

The SI pressure unit is the Pascal (Pa) = 1 Newton m^{-2}.
1 Torr = 1 mm Hg = 1.33322x10^{-3} bar =133.3 Pa.
1 Kilobar = 100 MPa.

TABLE 4. Conversion Factors for Energy Units

	erg	joule	calorie (g)	watt-hr	BTU	ev
1 erg=	1	10^{-7}	2.39006 x10^{-8}	2.778 x10^{-11}	9.4845 x10^{-11}	6.242 x10^{11}
1 joule=	10^{7}	1	2.39006 x10^{-1}	2.778 x10^{-4}	9.4845 x10^{-4}	6.242 x10^{18}
1 calorie (g)=	4.184 x10^{7}	4.184	1	1.1622 x10^{-3}	3.9683 x10^{-3}	2.612 x10^{19}
1 watt-hr=	3.60 x10^{10}	3600	860.421	1	3.4144	2.247 x10^{22}
1 BTU=	1.05435 x10^{10}	1054.35	251.99576	2.92875 x10^{-1}	1	6.581 x10^{21}
1 eV=	1.602 x10^{-12}	1.602 x10^{-19}	3.829 x10^{-20}	4.450 x10^{-23}	1.519 x10^{-22}	1

The calorie (g) is the thermochemical caloric as defined by the U.S. National Bureau of Standards.
1 joule = 1 watt-sec.
1 atomic mass unit = 1.492x10^{-10} joule.

TABLE 5. Conversion Factors for Frequency and Energy Units used in Spectroscopy[a]

	Hz	cm^{-1}	$J\ mol^{-1}$	eV
1 Hz=	1	3.3356×10^{-11}	3.9915×10^{-10}	4.1353×10^{-15}
1 cm^{-1}=	2.9979×10^{10}	1	11.9660	1.2397×10^{-4}
1 J mol^{-1}=	2.5053×10^{9}	8.3567×10^{-2}	1	1.0360×10^{-5}
1 eV=	2.4182×10^{14}	8.0663×10^{3}	9.6522×10^{4}	1

[a]Conversion factors taken from [3]. 1 Kayser = 1 cm^{-1}

TABLE 6. Fundamental Physical Constants[a]

Quantity	Symbol	Value	SI Units
Universal Constants			
Speed of light in vacuum	c	299 792 458	m sec^{-1}
Permeability of vacuum	μ_0	$4\pi \times 10^{-7}$	N A^{-2}
Permittivity of vacuum	ε_0	$1/\mu_0 c^2$	
		= 8.854 187 817	10^{-12} F m^{-1}
Newtonian constant of gravitation	G	6.672 59(85)	10^{-11} $m^3 kg^{-1} sec^{-2}$
Planck constant	h	6.626 075 5(40)	10^{-34} J sec
in electron volts, $h/\{e\}$		4.135 669 2(12)	10^{-15} eV sec
$h/2\pi$	$\hbar$	1.054 572 66(63)	10^{-34} J sec
in electron volts, $\hbar/\{e\}$		6.582 122 0(20)	10^{-16} eV sec
Planck mass, $(\hbar c/G)^{1/2}$	m_p	2.176 71(14)	10^{-8} kg
Planck length, $\hbar/m_p c = (\hbar G/c^3)^{1/2}$	l_p	1.616 05(10)	10^{-35} m
Planck time, $l_p/c = (\hbar G/c^5)^{1/2}$	t_p	5.390 56(34)	10^{-44} sec
Physicochemical constants			
Avogadro constant	N_A	6.022 136 7(36)	10^{23} mol^{-1}
Atomic mass constant, $m(C^{12})/12$	m_u	1.660 540 2(10)	10^{-27} kg
in electron volts, $m_u c^2/\{e\}$		931.494 32(28)	MeV
Faraday constant	F	96 485.309(29)	C mol^{-1}
Molar Planck constant	$N_A h$	3.990 313 23(36)	10^{-10}J sec mol^{-1}
	$N_A hc$	0.119 626 58(11)	J m mol^{-1}
Molar gas constant	R	8.314 510(70)	J mol^{-1} K^{-1}
Boltzmann constant, R/N_A	k	1.380 658(12)	10^{-23} J K^{-1}
in electron volts, $k/\{e\}$		8.617 385(73)	10^{-5} eV K^{-1}
in hertz, k/h		2.083 674(18)	10^{10} Hz K^{-1}
in wavenumbers, k/hc		69.503 87(59)	m^{-1} K^{-1}
Molar volume (ideal gas), RT/p (at 273.15 K, 101 325 Pa)	V_m	22 414.10(19)	cm^3 mol^{-1}
Loschmidt constant, N_A/V_m	n_0	2.686 763(23)	10^{25} m^{-3}

TABLE 6. (continued)

Quantity	Symbol	Value	SI Units
Stefan-Boltzmann constant, $(\pi^2/60)k^4/\hbar^3c^2$	σ	5.670 51(19)	10^{-8} W $m^{-2}K^{-4}$
First radiation constant, $2\pi hc^2$	c_1	3.741 774 9(22)	10^{-16} W m^2
Second radiation constant, hc/k	c_2	0.014 387 69(12)	m K
Wien displacement law constant, $\lambda_{max}T=c_2/4.965\ 114\ 23...$	b	2.897 756(24)	10^{-3} m K
Electromagnetic constants			
Elementary charge	e	1.602 177 33(49)	10^{-19} C
	e/h	2.417 988 36(72)	10^{14} A J^{-1}
Magnetic flux quantum, $h/2e$	Φ_0	2.067 834 61(61)	10^{-15} Wb
Josephson frequency-voltage quotient	$2e/h$	4.835 976 7(14)	10^{14} Hz V^{-1}
Quantized Hall conductance	e^2/h	3.874 046 14(7)	10^{-5} S
Quantized Hall resistance, $h/e^2=\mu_0c/2\alpha$	R_H	25 812.805 6(12)	Ω
Bohr magneton, $e\hbar/2m_e$	μ_B	9.274 015 4(31)	10^{-24} J T^{-1}
in electron volts, $\mu_B/\{e\}$		5.788 382 63(52)	10^{-5} eV T^{-1}
in hertz, μ_B/h		1.399 624 18(42)	10^{10} Hz T^{-1}
in wavenumbers, μ_B/hc		46.686 437(14)	m^{-1} T^{-1}
in kelvins, μ_B/k		0.671 709 9(57)	K T^{-1}
Nuclear magneton, $e\hbar/2m_p$	μ_N	5.050 786 6(17)	10^{-27} J T^{-1}
in electron volts, $\mu_N/\{e\}$		3.152 451 66(28)	10^{-8} eV T^{-1}
in hertz, μ_N/h		7.622 591 4(23)	MHz T^{-1}
in wavenumbers, μ_N/hc		2.542 622 81(77)	10^{-2} m^{-1} T^{-1}
in kelvins, μ_N/k		3.658 246(31)	10^{-4} K T^{-1}
Atomic constants			
Fine-structure constant, $\mu_0ce^2/2h$	α	7.297 353 08(33)	10^{-3}
inverse fine-structure constant	α^{-1}	137.035 989 5(61)	
Rydberg constant, $m_ec\alpha^2/2h$	R_∞	10 973 731.534(13)	m^{-1}
in hertz, $R_\infty c$		3.289 841 949 9(39)	10^{15} Hz
in joules, $R_\infty hc$		2.179 874 1(13)	10^{-18} J
in eV, $R_\infty hc/\{e\}$		13.605 698 1(40)	eV
Bohr radius, $\alpha/4\pi R_\infty$	a_0	0.529 177 249(24)	10^{-10} m
Hartree energy, $e^2/4\pi\varepsilon_0a_0=2R_\infty hc$	E_h	4.359 748 2(26)	10^{-18} J
in eV, $E_h/\{e\}$		27.211 396 1(81)	eV
Quantum of circulation	$h/2m_e$	3.636 948 07(33)	10^{-4} m^2 sec^{-1}
Electron Constants			
Mass	m_e	9.109 389 7(54)	10^{-31} kg
in atomic mass units		5.485 799 03(13)	10^{-4} u
in electron volts, $m_ec^2/\{e\}$		0.510 999 06(15)	MeV
Electron-muon mass ratio	m_e/m_μ	4.836 332 18(71)	10^{-3}

TABLE 6. (continued)

Quantity	Symbol	Value	SI Units
Electron-proton mass ratio	m_e/m_p	5.446 170 13(11)	10^{-4}
Electron-deuteron mass ratio	m_e/m_d	2.724 437 07(6)	10^{-4}
Electron-α-particle mass ratio	m_e/m_α	1.370 933 54(3)	10^{-4}
Specific charge	$-e/m_e$	-1.758 819 62(53)	10^{11} C kg^{-1}
Molar mass	$M(e)$	5.485 799 03(13)	10^{-7} kg mol^{-1}
Compton wavelength, h/m_ec	λ_c	2.426 310 58(22)	10^{-12} m
Classical radius, $\alpha^2 a_0$	r_e	2.817 940 92(38)	10^{-15} m
Thomson cross section, $(8\pi/3)r_e^2$	σ_e	0.665 246 16(18)	10^{-28} m^2
Magnetic moment	μ_e	928.477 01(31)	10^{-26} J T^{-1}
in Bohr magnetons	μ_e/μ_B	1.001 159 652 193(10)	
in nuclear magnetons	μ_e/μ_N	1838.282 000(37)	
Magnetic moment anomaly, μ_e/μ_B-1	a_e	1.159 652 193(10)	10^{-3}
g-factor, $2(1+a_e)$	g_e	2.002 319 304 386(20)	
Electron-muon magnetic moment ratio	μ_e/μ_μ	206.766 967(30)	
Electron-proton magnetic moment ratio	μ_e/μ_p	658.210 688 1(66)	
Muon Constants			
Mass	m_μ	1.883 532 7(11)	10^{-28} kg
in atomic mass units		0.113 428 913(17)	u
in electron volts, $m_\mu c^2/\{e\}$		105.658 389(34)	MeV
Muon-electron mass ratio	m_μ/m_e	206.768 262(30)	
Molar mass	$M(\mu)$	1.134 289 13(17)	10^{-4} kg mol^{-1}
Magnetic moment	μ_μ	4.490 451 4(15)	10^{-26} J T^{-1}
in Bohr magnetons	μ_μ/μ_B	4.841 970 97(71)	10^{-3}
in nuclear magnetons	μ_μ/μ_N	8.890 598 1(13)	
Magnetic moment anomaly, $[\mu_\mu/(e\hbar/2m_\mu)]-1$	a_μ	1.165 923 0(84)	10^{-3}
g-factor, $2(1+a_\mu)$	g_μ	2.002 331 846(17)	
Muon-proton magnetic moment ratio	μ_μ/μ_p	3.183 345 47(47)	
Proton Constants			
Mass	m_p	1.672 623 1(10)	10^{-27} kg
in atomic mass units		1.007 276 470(12)	u
in electron volts, $m_pc^2/\{e\}$		938.272 31(28)	MeV
Proton-electron mass ratio	m_p/m_e	1836.152 701(37)	
Proton-muon mass ratio	m_p/m_μ	8.880 244 4(13)	
Specific charge	e/m_p	9.578 830 9(29)	10^{7} C kg^{-1}
Molar mass	$M(p)$	1.007 276 470(12)	10^{-3} kg mol^{-1}
Compton wavelength, h/m_pc	$\lambda_{c,p}$	1.321 410 02(12)	10^{-15} m
Magnetic moment	μ_p	1.410 607 61(47)	10^{-26} J T^{-1}
in Bohr magnetons	μ_p/μ_B	1.521 032 202(15)	10^{-3}
in nuclear magnetons	μ_p/μ_N	2.792 847 386(63)	
Shielded proton moment (H_2O,	μ_p'	1.410 571 38(47)	10^{-26} J T^{-1}

TABLE 6. (continued)

Quantity	Symbol	Value	SI Units
spherical sample, 25°C)			
Diamagnetic shielding correction for protons (H_2O, spherical sample, 25°C), $1-\mu_p'/\mu_p$	σ_{H2O}	25.689(15)	10^{-6}
Gyromagnetic ratio	γ_p	26 752.212 8(81)	10^4 sec^{-1} T^{-1}
uncorrected (H_2O, spherical sample, 25°C)	γ_p'	26 751.525 5(81)	10^4 sec^{-1} T^{-1}
Neutron Constants			
mass	m_n	1.674 928 6(10)	10^{-27} kg
in atomic mass units		1.008 664 904(14)	u
in electron volts, $m_nc^2/\{e\}$		939.565 63(28)	MeV
Neutron-electron mass ratio	m_n/m_e	1838.683 662(40)	
Neutron-proton mass ratio	m_n/m_p	1.001 378 404(9)	
Molar mass	M(n)	1.008 664 904(14)	10^{-3} kg mol^{-1}
Compton wavelength, h/m_nc	$\lambda_{C,n}$	1.319 591 10(12)	10^{-15} m
Magnetic moment	μ_n	0.966 237 07(40)	10^{-26} J T^{-1}
in Bohr magnetons	μ_n/μ_B	1.041 875 63(25)	10^{-3}
in nuclear magnetons	$\mu_n\mu_N$	1.913 042 75(45)	
Neutron-electron magnetic moment ratio	μ_n/μ_e	1.040 668 82(25)	10^{-3}
Neutron-proton magnetic moment ratio	μ_n/μ_p	0.684 979 34(16)	
Deuteron Constants			
mass	m_d	3.343 586 0(20)	10^{-27} kg
in atomic mass units		2.013 553 214(24)	u
in electron volts, $m_dc^2/\{e\}$		1875.613 39(57)	MeV
Deuteron-electron mass ratio	m_d/m_e	3670.483 014(75)	
Deuteron-proton mass ratio	m_d/m_p	1.999 007 496(6)	
Molar mass	M(d)	2.013 553 214(24)	10^{-3} kg mol^{-1}
Magnetic moment	μ_d	0.433 073 75(15)	10^{-26} J T^{-1}
in Bohr magnetons	μ_d/μ_B	0.466 975 447 9(91)	10^{-3}
in nuclear magnetons	μ_d/μ_N	0.857 438 230(24)	
Deuteron-electron magnetic moment ratio	μ_d/μ_e	0.466 434 546 0(91)	
Deuteron-proton magnetic moment ratio	μ_d/μ_p	0.307 012 203 5(51)	
Conversion Factors and Units			
Electron volt, (e/C)J={e}J	eV	1.602 177 33(49)	10^{-19}J
Atomic mass unit (unified), $m_u=m(C^{12})/12$	u	1.660 540 2(10)	10^{-27} kg
Standard atmosphere	atm	101 325	Pa

TABLE 6. (continued)

Quantity	Symbol	Value	SI Units
Standard acceleration of gravity	g_n	9.806 65	m sec^{-2}
X-ray standards			
Cu x-unit: $\lambda(CuK\alpha_1) \equiv 1537.400$ xu	xu($CuK\alpha_1$)	1.002 077 89(70)	10^{-13} m
Mo x-unit: $\lambda(MoK\alpha_1) \equiv 707.831$ xu	xu($MoK\alpha_1$)	1.002 099 38(45)	10^{-13} m
Å*: $\lambda(WK\alpha_1) \equiv 0.209\ 100$ Å	Å*	1.000 014 81(92)	10^{-10} m
Lattice spacing of Si (in vacuum, 22.5°C)	a	0.543 101 96(11)	nm
$d_{220}=a/\sqrt{8}$	d_{220}	0.192 015 540(40)	nm
Molar volume of Si, $M(Si)/\rho(Si)=N_A a^3/8$	$V_m(Si)$	12.058 817 9(89)	cm^3 mol^{-1}

[a]Values are the set of recommended values of fundamental physical constants resulting from the 1986 least-squares adjustment [4] and recommended by CODATA, the Committee for Science and Technology of the International Council of Scientific Union. Digits in parentheses indicate the standard deviation uncertainty in the last digits of the given value. {e} refers to the numerical value only. The abbreviations for the units are: A=ampere; Å=angstrom; C=coulomb; eV=electron-volt; F=farad; Hz=hertz; J=joule; K=kelvin; kg= kilogram; m=meter; nm= nanometer; mol= mole; N=newton; Pa=pascal; S=siemen; T=tesla; u=unified mass unit; V=volt; W=watt; Wb=weber; Ω=ohm.

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