

APPENDIX A

THE INTERNATIONAL SYSTEM OF UNITS

The Système International d'Unités, abbreviated SI, is the system developed by the General Conference on Weights and Measures and adopted by nearly all the industrial nations of the world. The following material is adapted from B. N. Taylor, ed., National Institute of Standards and Technology Spec. Pub. 811 (U.S. Govt. Printing Office, Washington, DC, 1995). See also <http://physics.nist.gov/cuu>

Quantity	Name of unit	Symbol	
SI base units			
length	meter	m	
mass	kilogram	kg	
time	second	s	
electric current	ampere	A	
thermodynamic temperature	kelvin	K	
amount of substance	mole	mol	
luminous intensity	candela	cd	
SI derived units			Equivalent units
area	square meter	m ²	
volume	cubic meter	m ³	
frequency	hertz	Hz	s ⁻¹
mass density (density)	kilogram per cubic meter	kg/m ³	
speed, velocity	meter per second	m/s	
angular velocity	radian per second	rad/s	
acceleration	meter per second squared	m/s ²	
angular acceleration	radian per second squared	rad/s ²	
force	newton	N	kg · m/s ²
pressure (mechanical stress)	pascal	Pa	N/m ²
kinematic viscosity	square meter per second	m ² /s	
dynamic viscosity	newton-second per square meter	N · s/m ²	
work, energy, quantity of heat	joule	J	N · m
power	watt	W	J/s
quantity of electricity	coulomb	C	A · s
potential difference, electromotive force	volt	V	J/C, W/A
electric field strength	volt per meter	V/m	N/C
electric resistance	ohm	Ω	V/A
capacitance	farad	F	A · s/V
magnetic flux	weber	Wb	V · s
inductance	henry	H	V · s/A
magnetic flux density	tesla	T	Wb/m ²
magnetic field strength	ampere per meter	A/m	
magnetomotive force	ampere	A	
luminous flux	lumen	lm	cd · sr
luminance	candela per square meter	cd/m ²	
illuminance	lux	lx	lm/m ²
wave number	1 per meter	m ⁻¹	
entropy	joule per kelvin	J/K	
specific heat capacity	joule per kilogram-kelvin	J/kg · K	
thermal conductivity	watt per meter-kelvin	W/m · K	

APPENDIX B

USEFUL MATHEMATICAL RELATIONS

Algebra

$$a^{-x} = \frac{1}{a^x} \quad a^{(x+y)} = a^x a^y \quad a^{(x-y)} = \frac{a^x}{a^y}$$

Logarithms: If $\log a = x$, then $a = 10^x$. $\log a + \log b = \log(ab)$ $\log a - \log b = \log(a/b)$ $\log(a^n) = n \log a$
 If $\ln a = x$, then $a = e^x$. $\ln a + \ln b = \ln(ab)$ $\ln a - \ln b = \ln(a/b)$ $\ln(a^n) = n \ln a$

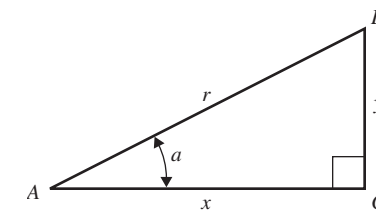
Quadratic formula: If $ax^2 + bx + c = 0$, $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$.

Binomial Theorem

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

Trigonometry

In the right triangle ABC , $x^2 + y^2 = r^2$.



Definitions of the trigonometric functions: $\sin a = y/r$ $\cos a = x/r$ $\tan a = y/x$

Identities: $\sin^2 a + \cos^2 a = 1$

$$\tan a = \frac{\sin a}{\cos a}$$

$$\sin 2a = 2 \sin a \cos a$$

$$\cos 2a = \cos^2 a - \sin^2 a = 2 \cos^2 a - 1 = 1 - 2 \sin^2 a$$

$$\sin \frac{1}{2} a = \sqrt{\frac{1 - \cos a}{2}}$$

$$\cos \frac{1}{2} a = \sqrt{\frac{1 + \cos a}{2}}$$

$$\sin(-a) = -\sin a$$

$$\sin(a \pm b) = \sin a \cos b \pm \cos a \sin b$$

$$\cos(-a) = \cos a$$

$$\cos(a \pm b) = \cos a \cos b \mp \sin a \sin b$$

$$\sin(a \pm \pi/2) = \pm \cos a$$

$$\sin a + \sin b = 2 \sin \frac{1}{2}(a + b) \cos \frac{1}{2}(a - b)$$

$$\cos(a \pm \pi/2) = \mp \sin a$$

$$\cos a + \cos b = 2 \cos \frac{1}{2}(a + b) \cos \frac{1}{2}(a - b)$$

Geometry

Circumference of circle of radius r :	$C = 2\pi r$
Area of circle of radius r :	$A = \pi r^2$
Volume of sphere of radius r :	$V = 4\pi r^3/3$
Surface area of sphere of radius r :	$A = 4\pi r^2$
Volume of cylinder of radius r and height h :	$V = \pi r^2 h$

Quantity	Name of unit	Symbol	Equivalent units
radiant intensity	watt per steradian	W/sr	
activity (of a radioactive source)	becquerel	Bq	s^{-1}
radiation dose	gray	Gy	J/kg
radiation dose equivalent	sievert	Sv	J/kg
SI supplementary units			
plane angle	radian	rad	
solid angle	steradian	sr	

Definitions of SI Units

meter (m) The *meter* is the length equal to the distance traveled by light, in vacuum, in a time of $1/299,792,458$ second.

kilogram (kg) The *kilogram* is the unit of mass; it is equal to the mass of the international prototype of the kilogram. (The international prototype of the kilogram is a particular cylinder of platinum-iridium alloy that is preserved in a vault at Sèvres, France, by the International Bureau of Weights and Measures.)

second (s) The *second* is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

ampere (A) The *ampere* is that constant current that, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length.

kelvin (K) The *kelvin*, unit of thermodynamic temperature, is the fraction $1/273.16$ of the thermodynamic temperature of the triple point of water.

ohm (Ω) The *ohm* is the electric resistance between two points of a conductor when a constant difference of potential of 1 volt, applied between these two points, produces in this conductor a current of 1 ampere, this conductor not being the source of any electromotive force.

coulomb (C) The *coulomb* is the quantity of electricity transported in 1 second by a current of 1 ampere.

candela (cd) The *candela* is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of $1/683$ watt per steradian.

mole (mol) The *mole* is the amount of substance of a system that contains as many elementary entities as there are carbon atoms in 0.012 kg of carbon 12. The elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

newton (N) The *newton* is that force that gives to a mass of 1 kilogram an acceleration of 1 meter per second per second.

joule (J) The *joule* is the work done when the point of application of a constant force of 1 newton is displaced a distance of 1 meter in the direction of the force.

watt (W) The *watt* is the power that gives rise to the production of energy at the rate of 1 joule per second.

volt (V) The *volt* is the difference of electric potential between two points of a conducting wire carrying a constant current of 1 ampere, when the power dissipated between these points is equal to 1 watt.

weber (Wb) The *weber* is the magnetic flux that, linking a circuit of one turn, produces in it an electromotive force of 1 volt as it is reduced to zero at a uniform rate in 1 second.

lumen (lm) The *lumen* is the luminous flux emitted in a solid angle of 1 steradian by a uniform point source having an intensity of 1 candela.

farad (F) The *farad* is the capacitance of a capacitor between the plates of which there appears a difference of potential of 1 volt when it is charged by a quantity of electricity equal to 1 coulomb.

henry (H) The *henry* is the inductance of a closed circuit in which an electromotive force of 1 volt is produced when the electric current in the circuit varies uniformly at a rate of 1 ampere per second.

radian (rad) The *radian* is the plane angle between two radii of a circle that cut off on the circumference an arc equal in length to the radius.

steradian (sr) The *steradian* is the solid angle that, having its vertex in the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides of length equal to the radius of the sphere.

SI Prefixes The names of multiples and submultiples of SI units may be formed by application of the prefixes listed in Appendix F.

Calculus

Derivatives:

$$\frac{d}{dx}x^n = nx^{n-1}$$

$$\frac{d}{dx}\sin ax = a\cos ax$$

$$\frac{d}{dx}\cos ax = -a\sin ax$$

$$\frac{d}{dx}e^{ax} = ae^{ax}$$

$$\frac{d}{dx}\ln ax = \frac{1}{x}$$

$$\int \frac{dx}{\sqrt{a^2 - x^2}} = \arcsin \frac{x}{a}$$

$$\int \frac{dx}{\sqrt{x^2 + a^2}} = \ln(x + \sqrt{x^2 + a^2})$$

$$\int \frac{dx}{x^2 + a^2} = \frac{1}{a} \arctan \frac{x}{a}$$

$$\int \frac{dx}{(x^2 + a^2)^{3/2}} = \frac{1}{a^2} \frac{x}{\sqrt{x^2 + a^2}}$$

$$\int \frac{xdx}{(x^2 + a^2)^{3/2}} = -\frac{1}{\sqrt{x^2 + a^2}}$$

Power series (convergent for range of x shown):

$$(1 + x)^n = 1 + nx + \frac{n(n-1)x^2}{2!} + \frac{n(n-1)(n-2)}{3!}x^3 + \dots \quad (|x| < 1)$$

$$\sin x = x - \frac{x^3}{3!} + \frac{x^5}{5!} - \frac{x^7}{7!} + \dots \quad (\text{all } x)$$

$$\cos x = 1 - \frac{x^2}{2!} + \frac{x^4}{4!} - \frac{x^6}{6!} + \dots \quad (\text{all } x)$$

$$\tan x = x + \frac{x^3}{3} + \frac{2x^5}{15} + \frac{17x^7}{315} + \dots \quad (|x| < \pi/2)$$

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots \quad (\text{all } x)$$

$$\ln(1 + x) = x - \frac{x^2}{2} + \frac{x^3}{3} - \frac{x^4}{4} + \dots \quad (|x| < 1)$$

Integrals:

$$\int x^n dx = \frac{x^{n+1}}{n+1} \quad (n \neq -1)$$

$$\int \frac{dx}{x} = \ln x$$

$$\int \sin ax dx = -\frac{1}{a} \cos ax$$

$$\int \cos ax dx = \frac{1}{a} \sin ax$$

$$\int e^{ax} dx = \frac{1}{a} e^{ax}$$

APPENDIX C

THE GREEK ALPHABET

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

APPENDIX D

PERIODIC TABLE OF THE ELEMENTS

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period																		
1	1 H 1.008																	2 He 4.003
2	3 Li 6.941	4 Be 9.012											5 B 10.811	6 C 12.011	7 N 14.007	8 O 15.999	9 F 18.998	10 Ne 20.180
3	11 Na 22.990	12 Mg 24.305											13 Al 26.982	14 Si 28.086	15 P 30.974	16 S 32.065	17 Cl 35.453	18 Ar 39.948
4	19 K 39.098	20 Ca 40.078	21 Sc 44.956	22 Ti 47.867	23 V 50.942	24 Cr 51.996	25 Mn 54.938	26 Fe 55.845	27 Co 58.933	28 Ni 58.693	29 Cu 63.546	30 Zn 65.409	31 Ga 69.723	32 Ge 72.64	33 As 74.922	34 Se 78.96	35 Br 79.904	36 Kr 83.798
5	37 Rb 85.468	38 Sr 87.62	39 Y 88.906	40 Zr 91.224	41 Nb 92.906	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.906	46 Pd 106.42	47 Ag 107.868	48 Cd 112.411	49 In 114.818	50 Sn 118.710	51 Sb 121.760	52 Te 127.60	53 I 126.904	54 Xe 131.293
6	55 Cs 132.905	56 Ba 137.327	71 Lu 174.967	72 Hf 178.49	73 Ta 180.948	74 W 183.84	75 Re 186.207	76 Os 190.23	77 Ir 192.217	78 Pt 195.078	79 Au 196.967	80 Hg 200.59	81 Tl 204.383	82 Pb 207.2	83 Bi 208.980	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra (226)	103 Lr (262)	104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (269)	109 Mt (268)	110 Ds (271)	111 Rg (272)	112 Uub (285)	113 Uut (284)	114 Uuq (289)	115 Uup (288)	116 Uuh (292)	117 Uus (292)	118 Uuo (292)

Lanthanoids	57 La 138.905	58 Ce 140.116	59 Pr 140.908	60 Nd 144.24	61 Pm (145)	62 Sm 150.36	63 Eu 151.964	64 Gd 157.25	65 Tb 158.925	66 Dy 162.500	67 Ho 164.930	68 Er 167.259	69 Tm 168.934	70 Yb 173.04
Actinoids	89 Ac (227)	90 Th (232)	91 Pa (231)	92 U (238)	93 Np (237)	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)

For each element the average atomic mass of the mixture of isotopes occurring in nature is shown. For elements having no stable isotope, the approximate atomic mass of the longest-lived isotope is shown in parentheses. For elements that have been predicted but not yet detected, no atomic mass is given. All atomic masses are expressed in atomic mass units ($1 \text{ u} = 1.66053886(28) \times 10^{-27} \text{ kg}$), equivalent to grams per mole (g/mol).

APPENDIX E

UNIT CONVERSION FACTORS

Length

1 m = 100 cm = 1000 mm = $10^6 \mu\text{m}$ = 10^9nm
 1 km = 1000 m = 0.6214 mi
 1 m = 3.281 ft = 39.37 in.
 1 cm = 0.3937 in.
 1 in. = 2.540 cm
 1 ft = 30.48 cm
 1 yd = 91.44 cm
 1 mi = 5280 ft = 1.609 km
 1 Å = 10^{-10}m = 10^{-8}cm = 10^{-1}nm
 1 nautical mile = 6080 ft
 1 light year = $9.461 \times 10^{15} \text{m}$

Area

1 cm² = 0.155 in.²
 1 m² = 10^4cm^2 = 10.76 ft²
 1 in.² = 6.452 cm²
 1 ft = 144 in.² = 0.0929 m²

Volume

1 liter = 1000 cm³ = 10^{-3}m^3 = 0.03531 ft³ = 61.02 in.³
 1 ft³ = 0.02832 m³ = 28.32 liters = 7.477 gallons
 1 gallon = 3.788 liters

Time

1 min = 60 s
 1 h = 3600 s
 1 d = 86,400 s
 1 y = 365.24 d = $3.156 \times 10^7 \text{s}$

Angle

1 rad = 57.30° = $180^\circ/\pi$
 1° = 0.01745 rad = $\pi/180$ rad
 1 revolution = 360° = 2π rad
 1 rev/min (rpm) = 0.1047 rad/s

Speed

1 m/s = 3.281 ft/s
 1 ft/s = 0.3048 m/s
 1 mi/min = 60 mi/h = 88 ft/s
 1 km/h = 0.2778 m/s = 0.6214 mi/h
 1 mi/h = 1.466 ft/s = 0.4470 m/s = 1.609 km/h
 1 furlong/fortnight = $1.662 \times 10^{-4} \text{m/s}$

Acceleration

1 m/s² = 100 cm/s² = 3.281 ft/s²
 1 cm/s² = 0.01 m/s² = 0.03281 ft/s²
 1 ft/s² = 0.3048 m/s² = 30.48 cm/s²
 1 mi/h · s = 1.467 ft/s²

Mass

1 kg = 10³ g = 0.0685 slug
 1 g = 6.85×10^{-5} slug
 1 slug = 14.59 kg
 1 u = $1.661 \times 10^{-27} \text{kg}$
 1 kg has a weight of 2.205 lb when $g = 9.80 \text{m/s}^2$

Force

1 N = 10⁵ dyn = 0.2248 lb
 1 lb = 4.448 N = $4.448 \times 10^5 \text{dyn}$

Pressure

1 Pa = 1 N/m² = $1.450 \times 10^{-4} \text{lb/in.}^2$ = 0.209 lb/ft²
 1 bar = 10⁵ Pa
 1 lb/in.² = 6895 Pa
 1 lb/ft² = 47.88 Pa
 1 atm = $1.013 \times 10^5 \text{Pa}$ = 1.013 bar
 = 14.7lb/in.^2 = 2117 lb/ft²
 1 mm Hg = 1 torr = 133.3 Pa

Energy

1 J = 10⁷ ergs = 0.239 cal
 1 cal = 4.186 J (based on 15° calorie)
 1 ft · lb = 1.356 J
 1 Btu = 1055 J = 252 cal = 778 ft · lb
 1 eV = $1.602 \times 10^{-19} \text{J}$
 1 kWh = $3.600 \times 10^6 \text{J}$

Mass–Energy Equivalence

1 kg ↔ $8.988 \times 10^{16} \text{J}$
 1 u ↔ 931.5 MeV
 1 eV ↔ $1.074 \times 10^{-9} \text{u}$

Power

1 W = 1 J/s
 1 hp = 746 W = 550 ft · lb/s
 1 Btu/h = 0.293 W

APPENDIX F

NUMERICAL CONSTANTS

Fundamental Physical Constants*

Name	Symbol	Value
Speed of light	c	$2.99792458 \times 10^8 \text{m/s}$
Magnitude of charge of electron	e	$1.60217653(14) \times 10^{-19} \text{C}$
Gravitational constant	G	$6.6742(10) \times 10^{-11} \text{N} \cdot \text{m}^2/\text{kg}^2$
Planck's constant	h	$6.6260693(11) \times 10^{-34} \text{J} \cdot \text{s}$
Boltzmann constant	k	$1.3806505(24) \times 10^{-23} \text{J/K}$
Avogadro's number	N_A	$6.0221415(10) \times 10^{23} \text{molecules/mol}$
Gas constant	R	$8.314472(15) \text{J/mol} \cdot \text{K}$
Mass of electron	m_e	$9.1093826(16) \times 10^{-31} \text{kg}$
Mass of proton	m_p	$1.67262171(29) \times 10^{-27} \text{kg}$
Mass of neutron	m_n	$1.67492728(29) \times 10^{-27} \text{kg}$
Permeability of free space	μ_0	$4\pi \times 10^{-7} \text{Wb/A} \cdot \text{m}$
Permittivity of free space	$\epsilon_0 = 1/\mu_0 c^2$ $1/4\pi\epsilon_0$	$8.854187817 \dots \times 10^{-12} \text{C}^2/\text{N} \cdot \text{m}^2$ $8.987551787 \dots \times 10^9 \text{N} \cdot \text{m}^2/\text{C}^2$

Other Useful Constants*

Mechanical equivalent of heat		4.186 J/cal (15° calorie)
Standard atmospheric pressure	1 atm	$1.01325 \times 10^5 \text{Pa}$
Absolute zero	0 K	-273.15°C
Electron volt	1 eV	$1.60217653(14) \times 10^{-19} \text{J}$
Atomic mass unit	1 u	$1.66053886(28) \times 10^{-27} \text{kg}$
Electron rest energy	$m_e c^2$	0.510998918(44) MeV
Volume of ideal gas (0°C and 1 atm)		22.413996(39) liter/mol
Acceleration due to gravity (standard)	g	9.80665 m/s ²

*Source: National Institute of Standards and Technology (<http://physics.nist.gov/cuu>). Numbers in parentheses show the uncertainty in the final digits of the main number; for example, the number 1.6454(21) means 1.6454 ± 0.0021 . Values shown without uncertainties are exact.

Astronomical Data[†]

Body	Mass (kg)	Radius (m)	Orbit radius (m)	Orbit period
Sun	1.99×10^{30}	6.96×10^8	—	—
Moon	7.35×10^{22}	1.74×10^6	3.84×10^8	27.3 d
Mercury	3.30×10^{23}	2.44×10^6	5.79×10^{10}	88.0 d
Venus	4.87×10^{24}	6.05×10^6	1.08×10^{11}	224.7 d
Earth	5.97×10^{24}	6.38×10^6	1.50×10^{11}	365.3 d
Mars	6.42×10^{23}	3.40×10^6	2.28×10^{11}	687.0 d
Jupiter	1.90×10^{27}	6.91×10^7	7.78×10^{11}	11.86 y
Saturn	5.68×10^{26}	6.03×10^7	1.43×10^{12}	29.45 y
Uranus	8.68×10^{25}	2.56×10^7	2.87×10^{12}	84.02 y
Neptune	1.02×10^{26}	2.48×10^7	4.50×10^{12}	164.8 y
Pluto [‡]	1.31×10^{22}	1.15×10^6	5.91×10^{12}	247.9 y

[†]Source: NASA Jet Propulsion Laboratory Solar System Dynamics Group (<http://ssd.jpl.nasa.gov>), and P. Kenneth Seidelmann, ed., *Explanatory Supplement to the Astronomical Almanac* (University Science Books, Mill Valley, CA, 1992), pp. 704–706. For each body, “radius” is its radius at its equator and “orbit radius” is its average distance from the sun (for the planets) or from the earth (for the moon).

[‡]In August 2006, the International Astronomical Union reclassified Pluto and other small objects that orbit the sun as “dwarf planets.”

Prefixes for Powers of 10

Power of ten	Prefix	Abbreviation	Pronunciation
10^{-24}	yocto-	y	<i>yoc</i> -toe
10^{-21}	zepto-	z	<i>zep</i> -toe
10^{-18}	atto-	a	<i>at</i> -toe
10^{-15}	femto-	f	<i>fem</i> -toe
10^{-12}	pico-	p	<i>pee</i> -koe
10^{-9}	nano-	n	<i>nan</i> -oe
10^{-6}	micro-	μ	<i>my</i> -crow
10^{-3}	milli-	m	<i>mil</i> -i
10^{-2}	centi-	c	<i>cen</i> -ti
10^3	kilo-	k	<i>kil</i> -oe
10^6	mega-	M	<i>meg</i> -a
10^9	giga-	G	<i>jig</i> -a or <i>gig</i> -a
10^{12}	tera-	T	<i>ter</i> -a
10^{15}	peta-	P	<i>pet</i> -a
10^{18}	exa-	E	<i>ex</i> -a
10^{21}	zetta-	Z	<i>zet</i> -a
10^{24}	yotta-	Y	<i>yot</i> -a

Examples:

1 femtometer = 1 fm = 10^{-15} m

1 picosecond = 1 ps = 10^{-12} s

1 nanocoulomb = 1 nC = 10^{-9} C

1 microkelvin = 1 μ K = 10^{-6} K

1 millivolt = 1 mV = 10^{-3} V

1 kilopascal = 1 kPa = 10^3 Pa

1 megawatt = 1 MW = 10^6 W

1 gigahertz = 1 GHz = 10^9 Hz