13.1: Appendix A Constants, Units, and Conversions

Appendix A Constants, Units, and Conversions

This appendix contains various useful constants and conversion factors as well as information on the International System of Units.

Units

"SI" is the French abbreviation for the International System of Units, the system used universally in science. See http://physics.nist.gov/cuu/Units/ for the last word on this subject. This treatment is derived from the National Institute of Science and Technology (NIST) website.

The most fundamental units of measure are length (meters; m), mass (kilograms; kg), time (seconds; s), electric current (ampere; A), temperature (kelvin; K), amount of a substance (mole; mol), and the luminous intensity (candela; cd). The candela is a rather specialized unit related to the perceived brightness of a light source by a "standard" human eye. As such, it is rather anthropocentric and hardly seems to merit the designation "fundamental". The mole is also less fundamental than the other units, as it is simply a convenient way to refer to a multiple of Avogadro's number of atoms or molecules.

Fundamental units can be combined to form derived units with special names. Some of these derived units are listed below.

Fundamental and derived SI units can have multipliers expressed as prefixes, e. g., 1 km = 1000 m. The NIST website points out a minor irregularity with the fundamental unit of mass, the kilogram. This already has the multiplier "kilo" prefixed to the unit "gram". In this case 1000 kg is written 1 Mg, not 1 kkg, etc. SI multipliers are listed below as well.

Derived Units

Name	Abbrev.	Units	Meaning
hertz	Hz	s^{-1}	frequency (cycles/sec)
(unnamed)		s^{-1}	angular frequency (radians/sec)
newton	N	$kg\ m\ s^{-2}$	force
pascal	Pa	$N\ m^{-2}$	pressure
joule	J	N m	energy
watt	W	$J\ s^{-1}$	power
coulomb	C	A s	electric charge
volt	V	$N\ m\ C^{-1}$	scalar potential
(unnamed)		$N\ s\ C^{-1}$	vector potential
(unnamed)		$V\ m^{-1}$	electric field
tesla	T	$N\ s\ C^{-1}\ m^{-1}$	magnetic field
(unnamed)		V m	electric flux
weber	Wb	$T\ m^2$	magnetic flux
volt	V	V	electric circulation (EMF)
(unnamed)		T m	magnetic circulation
farad	F	$C\ V^{-1}$	capacitance
ohm	Ω	$V\ A^{-1}$	resistance
henry	H	$V\ s^2\ C^{-1}$	inductance

Multipliers

Multiplier	Name	Prefix
10^{24}	yotta	Y
10^{21}	zetta	Z
10^{18}	exa	E
10^{15}	peta	P
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a
10^{-21}	zepto	z
10^{-24}	yocto	y

Centimeter-Gram-Second Units

An older system of scientific units is the CGS system. This system is still used widely in certain areas of physics. The fundamental units of length, mass, and time are as implied by the title given above. The most common CGS derived units are those for force (1 dyne = 10^{-5} N) and energy (1 erg = 10^{-7} J).

Electromagnetism is expressed in several different ways in CGS units. Electromagnetic quantities in CGS not only have different units than in SI, they also have different physical dimensions, with different versions differing among themselves. The most common variant of CGS electromagnetic units is called “Gaussian” units. This variant is advocated by some physicists, though many others consider the whole subject of CGS electromagnetic units to be a terrible mess! SI units for electromagnetism are used in this text and CGS units will not be discussed further here.

Miscellaneous Conversions

1 lb = 4. 448 N
1 ft = 0. 3048 m
1 mph = 0. 4470 m s^{-1}
1 eV = 1. 60 × 10^{-19} J

1 mol = 6. 022 × 10^{23} molecules
1 gauss = 10^{-4} T (CGS unit of magnetic field)
1 millibar = 1 mb = 100 Pa (Old unit of pressure)

Advice on Calculations

Substituting Numbers

When faced with solving an algebraic equation to obtain a numerical answer, solve the equation symbolically first and then substitute numbers. For example, given the equation

$$ax^2 - b = 0 \tag{13.1.1}$$	(A.1)

where a = 2 and b = 8, first solve for x,

$$1/2x = \pm(b/a), \tag{13.1.2}$$	(A.2)

and then substitute the numerical values:

$$1/21/2x = \pm(8/2) = \pm 4 = \pm 2. \tag{13.1.3}$$	(A.3)

This procedure is far better than substituting numbers first,

$$2x^2 - 8 = 0 \tag{13.1.4}$$	(A.4)

and then solving for x. Solving first and then substituting has two advantages: (1) It is easier to make algebraic manipulations with symbols than it is with numbers. (2) If you decide later that numerical values should be different, then the entire solution procedure doesn't have to be repeated, only the substitutions at the end.

Significant Digits

In numerical calculations, keep only one additional digit beyond those present in the least accurate input number. For instance, if you are taking the square root of 3. 4, your calculator might tell you that the answer is 1. 843908891. The answer you write down should be 1. 84. Keeping all ten digits of the calculator's answer gives a false sense of the accuracy of the result.

Round the result up if the digit following the last significant digit is 5 or greater and round it down if it is less than 5. Thus, the square root of 4. 1, which the calculator tells us is 2. 049390153, should be represented as 2. 05 rather than 2. 04.

Changing Units

It is easy to make mistakes when changing the units of a quantity. Adopting a systematic approach to changing units greatly reduces the chance of error. We illustrate a systematic approach to this problem with an example in which we change the units of acceleration from meters per second squared to kilometers per minute squared:

$$\begin{aligned} 5\ \mathrm{m/s^2} &\rightarrow 5\ \mathrm{m/s^2} \times (0.001\ \mathrm{km/m}) \times (60\ \mathrm{s/min})^2 \\ &= 5 \times 0.001 \times 60^2\ \mathrm{km/min^2} \\ &= 18\ \mathrm{km/min^2} \end{aligned} \tag{13.1.5}$$

The trick is to multiply by the conversion factor for each unit to the power that makes the original unit cancel out. The conversion factors to the proper powers are then multiplied by the original number and the proper cancellations of the old units are double checked. If done with care, this yields the correct result every time!

Constants of Nature

Symbol	Value	Meaning
h	6.63×10^{-34} J s	Planck's constant
$\hbar$	1.06×10^{-34} J s	$h/(2\pi)$
c	2.998×10^{8} m s^{-1}	speed of light
G	6.67×10^{-11} m^3 s^{-2} kg^{-1}	universal gravitational constant
k_B	1.38×10^{-23} J K^{-1}	Boltzmann's constant
σ	5.67×10^{-8} W m^{-2} K^{-4}	Stefan-Boltzmann constant
K	3.67×10^{11} s^{-1} K^{-1}	thermal frequency constant
ϵ_0	8.85×10^{-12} C^2 N^{-1} m^{-2}	permittivity of free space
μ_0	$4\pi \times 10^{-7}$ N s^2 C^{-2}	permeability of free space (= $1/(\epsilon_0 c^2)$).

Properties of Stable Particles

Symbol	Value	Meaning
e	1.60×10^{-19} C	fundamental unit of charge
m_e	9.11×10^{-31} kg = 0.511 MeV	mass of electron
m_p	1.672648×10^{-27} kg = 938.280 MeV	mass of proton
m_n	1.674954×10^{-27} kg = 939.573 MeV	mass of neutron

Properties of Solar System Objects

Symbol	Value	Meaning
M_e	5.98×10^{24} kg	mass of earth
M_m	7.36×10^{22} kg	mass of moon
M_s	1.99×10^{30} kg	mass of sun
R_e	6.37×10^{6} m	radius of earth
R_m	1.74×10^{6} m	radius of moon
R_s	6.96×10^{8} m	radius of sun
D_m	3.82×10^{8} m	earth-moon distance
D_s	1.50×10^{11} m	earth-sun distance
g	9.81 m s^{-2}	earth's surface gravity