4

Units, Conversions, and Constants

4.1 THE INTERNATIONAL SYSTEM OF UNITS (SI)

Quantities are physical characteristics capable of being expressed numerically. Examples are length, pressure, and electric current. *Units* are arbitrary amounts that form the basis for measurement of quantities. Examples are centimeters, pounds per square inch, and amperes. The *Systeme Internationale d'Unites* (SI) has been developed to provide a single, well-defined, and universally accepted unit for each quantity.

Quantity symbols:

1. Quantity symbols consist of a single letter of the English or Greek alphabet, modified by subscripts and/or superscripts as appropriate.

2. When printed, quantity symbols (and mathematical variables) appear in *italic* (slanted) type. Subscripts that are quantity symbols in their own right are also italic. Other subscripts are roman (upright). Examples are

$$V_R\,,\ V_{\mathrm{max}}\,,\ I_x\,,\ I_{\mathrm{CEO}}$$

3. Boldface italic type may be used to distinguish a vector quantity ($\boldsymbol{I}$) from a scalar quantity (I). If lightface is used for vectors, then magnitudes should be distinguished by the *absolute* sign: $|I|$.

4. Because of the limited number of characters available, two quantities may be assigned the same letter symbol. To avoid confusion, an alternative letter symbol may be employed if one is listed, or the quantities may be differentiated by subscripts, or upper- and lowercase letters may be defined differently by the writer. In all cases the same quantity symbol should be retained throughout the work. Examples of such differentiations follow:

t (time), θ (temperature)
t (time), t_p (temperature)
t (time), T (temperature)

5. Several subscripts may be attached to a single quantity symbol, separated by a comma, hyphen, or parentheses if necessary for clarity. Multiple-level subscripts (subscripts attached to subscripts) are discouraged. A symbol with a superscript should be enclosed in parentheses before an exponent is added.

Electrical quantity symbols follow several additional conventions. Figure 4.1 illustrates some of them.

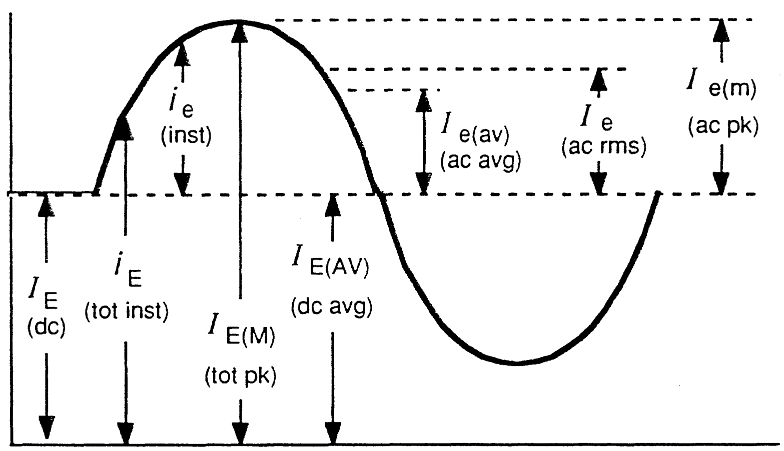

Figure 4.1 Quantity-symbol and subscript usage.

6. Uppercase (capital) letters are used for the quantity symbols for voltage, current, and power to designate dc, rms, average (av), maximum (m), or minimum (n, for *nadir*: lowest point) values. Uppercase subscripts to uppercase quantity symbols indicate dc values, or, with the subscripts M, AV, or N, respectively, the maximum, average, or minimum value of the total waveform. Lowercase subscripts to uppercase quantity symbols indicate the rms value of the ac wave, or with the subscript "m" the maximum value of the ac component of the total wave.

7. Lowercase (small) letters are used to designate the instantaneous value of a time-varying quantity. Here uppercase subscripts indicate the instantaneous value of the total waveform (dc + ac), and lowercase subscripts indicate the instantaneous value of the ac component only.

8. Double-uppercase subscripts designate the dc supply for the element indicated. Example: V_{CC} for the dc collector supply voltage.

9. Two-letter subscripts to the voltage symbol designate voltage from the first point to the second point as a reference. Single-letter subscripts to the voltage symbol may indicate voltage across the indicated device, or from the point designated to circuit ground as a reference.

Examples:	V_{CE}	(collector to emitter)
	V_Z	(across the zener diode)
	V_C	(collector to ground)
	V_o	(output to ground, ac)

10. Hyphenated subscripts may be used where two elements have the same name:

Examples:	$V_{B1\text{-}B2}$	(base 1 to base 2 of UJT)
	$V_{1B\text{-}2B}$	(base of the first transistor to base of the second)

11. Conventional current (positive to negative through the load) is regarded as flowing *into* the terminal indicated by a subscript to the current symbol. Conventional current out of the terminal gives the quantity a negative sign.

Figure 4.2, on the following page, shows this standard applied to one TTL gate driving another. The input delivers current back to the output of the driver in TTL, but the current leaving the input is designated as negative, and the same current entering the output is designated as positive.

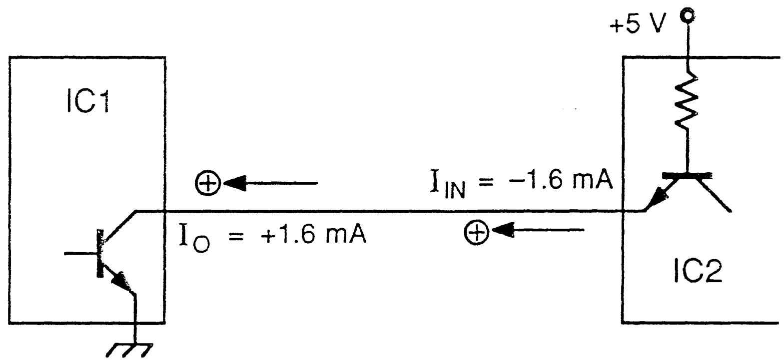

Figure 4.2. Current entering a device is positive. Current leaving a device is negative.

12. Bulk resistance is total voltage divided by total current, and is designated by uppercase R. Dynamic resistance ($\Delta V / \Delta I$) is designated by lowercase r. Lowercase r may also be used to designate inherent resistance of devices such as signal sources, inductors, and semiconductors.

Unit symbols consist of a letter or group of letters from the English and Greek alphabets, plus a few special symbols.

1. Unit symbols are printed in roman (upright) type. They are never given subscripts or superscripts.

2. Lowercase letters are used for unit symbols except where the symbol was derived from a proper name, in which case the first letter is capitalized.

3. A space is left between the number and the unit symbol.

4. Compound units, formed by multiplication and/or division of basic units, are common. Use a raised period to separate multiplications and a solidus (slash) or negative exponent to indicate division.

Examples: N·m for newton-meters, and W/m^2 or $W \cdot m^{-2}$ for watts per square meter.

5. Clarity of meaning is often served by expressing certain quantities in "phantom" units. These should be reduced to strict SI units for purposes of calculation. Examples follow.

- Radian/second, cycle/second, and revolution/second reduce to 1/s.
- Ampere·turn for magnetomotive force reduces to A.

- V/V, mV/V, and so on for gain, regulation, common-mode rejection ratio, and so on, reduce to a unitless quantity.
- Meters/meter, µinch/inch, and so on, for strain, reduce to a unitless quantity.
- Ω/square for sheet resistivity reduces to Ω.
- Ω·cm^2/cm for bulk resistivity reduces to Ω·cm.

6. In typewritten work, substitute u for µ (adding the "tail" by hand if possible), substitute ohm for Ω, and use underline to indicate italic (V̲ for *V*), if necessary, to eliminate confusion.
7. Unit prefixes may be added in front of the SI unit symbol to avoid excessively large or small numbers and the power-of-ten notation. Prefixes are selected to place the number in the range from 0.1 to 1000.
8. The term "billion" and the practice of separating digits into groups of three with commas should be avoided because of conflicting meanings outside the United States. Use a space between groups of three digits for numbers above 9999. For example, write 98 765 432, not 98,765,432.

Common improper or obsolete usages of quantity and unit symbols are illustrated in the table below.

Not Recommended	*Proper Form*
v = 15 fps	v = 15 ft/s
psig = 14.7	p_g = 14.7 lb/in^2
E_p = 117 VAC	V_p = 117 V ac
dB = 12	α = 12 dB
I = 1.5 A_{rms}	I_{rms} = 1.5 A
f = 60 cps	f = 60 Hz
f = 16 Kc	f = 16 kHz
G = 50 mµ℧	G = 50 nS
C = 8 MFD	C = 8 µF
C = 47 µµF	C = 47 pF

4.2 QUANTITY, UNIT, AND UNIT-PREFIX SYMBOLS

Base units. SI is based on the independently defined units given in the table below.

Quantity	*Unit Name*	*Unit Symbol*
Length, l	meter	m
Mass, m	kilogram	kg
Time, t	second	s
Electric current, I	ampere	A
Temperature, T	kelvin	K
Amount of substance	mole	mol
Luminous intensity, I_v	candela	cd
Plane angle, θ	radian	rad
Solid angle, Ω	steradian	sr

• Kilogram is the basic unit of mass. *Kilo* is not regarded here as a prefix. However, additional prefixes should be reduced. For example, microkilogram should be expressed as milligram.

• Kelvin (K), not degree kelvin nor °K, is the basic unit of temperature. However the use of the word *degree* and the symbol (°) are to be continued with °C, °F, and °R.

• A *mole* of any substance contains 6.02257×10^{23} atoms, molecules, ions, or radicals of that substance.

• A *candela* is slightly less than the illumination given by one standard candle (candlepower), and is defined as the amount of light given off by solidifying platinum (1772 °C) through a hole 1 cm^2 in area.

• A radian is an angle constructed from the center of a circle such that the arc length equals the radius. There are 2π radians in a circle. A steradian is an angle constructed in a sphere such that the surface area equals the radius squared. There are 4π steradians in a sphere.

Derived units that have been given special names are listed in the table on the following page. All SI measurements are to be expressed by combinations of base and derived units.

Derived SI Units

Quantity	*Unit Name*	*Unit Symbol*	*Formula*	*SI Base Units*
Force, F	newton	N	$kg{\cdot}m/s^2$	$kg{\cdot}m/s^2$
Pressure, stress, p	pascal	Pa	N/m^2	$kg/m{\cdot}s^2$
Energy, work, W	joule	J	$N{\cdot}m$	$kg{\cdot}m^2/s^2$
Power, P	watt	W	J/s	$kg{\cdot}m^2/s^3$
Charge, Q	coulomb	C	$A{\cdot}s$	$A{\cdot}s$
EMF, V	volt	V	W/A	$kg{\cdot}m^2/A{\cdot}s^3$
Resistance, R	ohm	Ω	V/A	$kg{\cdot}m^2/A^2{\cdot}s^3$
Conductance, G	siemens	S	A/V	$A^2{\cdot}s^3/kg{\cdot}m^2$
Capacitance, C	farad	F	C/V	$kg{\cdot}m^2/s^2$
Inductance, L	henry	H	Wb/A	$kg{\cdot}m^2/A^2{\cdot}s^2$
Magnetic flux, φ	weber	Wb	$V{\cdot}s$	$kg{\cdot}m^2/A{\cdot}s^2$
Flux density, B	tesla	T	Wb/m^2	$kg/A{\cdot}s^2$
Frequency, f	hertz	Hz	1/s	s^{-1}
Luminous flux, φ_v	lumen	lm	$cd{\cdot}sr$	$cd{\cdot}sr$
Illumination, E_v	lux	lx	lm/m^2	$cd{\cdot}sr/m^2$

Magnetic quantities and units are less widely understood than their electrical counterparts, perhaps because magnetic measuring instruments are less common. The table below lists comparable units as an aid to conceptualization.

Electrical Units			Magnetic Units		
Quantity	*Symbol*	*Unit*	*Quantity*	*Symbol*	*Unit*
EMF	V	V	Magnetomotive force	F_m	A
Field strength	E	V/m	Magnetization	H	A/m
Current	I	A	Magnetic flux	φ	Wb
Current density	J	A/m^2	Flux density	B	T
Resistance	R	Ω	Reluctance	R_m	H^{-1}
Resistivity	ρ	$\Omega{\cdot}m$	Reluctivity	ν	m/H
Conductance	G	S	Permeance	P_m	H
Conductivity	γ	S/m	Permeability	μ	H/m
Relative conductivity	—	—	Relative permeability	μ_r	— (numeric)

Magnetic "Hand" Rules

Field about a wire. Grasp a wire with the right hand, the thumb pointing in the direction of conventional current (positive to negative). The fingers curl around the wire in the direction of the magnetic lines of force (N to S).

Solenoid magnetic polarity. Grasp the coil with the right hand, the fingers curling around in the direction of conventional current. The thumb points to the north pole of the solenoid.

Direction of induced current. Point the index finger of the right hand in the direction of lines of force (N to S) and the thumb in the direction of motion of the conductor. The middle finger (bent toward the palm) points in the direction of induced conventional current.

Force on a moving charge. Point the index finger of the *left* hand in the direction of lines of force (N to S), and the middle finger (bent) in the direction of conventional current. The thumb points in the direction of the force on the charge.

Light is normally measured in the *photometric* system, which includes only the portion of the electromagnetic spectrum visible to the human eye. The *radiometric* system includes all wavelengths of electromagnetic radiation. The two systems are compared in thte table below.

Photometric vs. Radiometric Quantity and Unit Symbols

	Photometric			*Radiometric*	
Quantity	*Symbol*	*Unit*	*Comment*	*Symbol*	*Unit*
Source intensity	I_v	cd	cd = lm/sr	I_e	W/sr
Luminous flux (power)	ϕ_v	lm	lm = cd·sr	ϕ_e	W
Illumination (irradiance)	E_v	lx	lx = lm/m^2	E_e	W/m^2
Efficacy	K	lm/W	$\frac{\text{visible light}}{\text{total power}}$	—	—

SI quantity and unit symbols (other than magnetic and light) are given in the table below. Symbols in parentheses are reserve quantity symbols to be used only to avoid conflicting symbol meanings.

Additional Quantity and SI Unit Symbols

Quantity	*Symbol*	*Unit*
Spatial		
Plane angle	$\theta, \phi, \alpha, \beta$	rad
Solid angle	Ω, (ω)	sr
Length	l	m
Path length	s	m
Thickness	d, δ	m
Radius	r	m
Diameter	d	m
Area	A, (S)	m^2
Volume	V, v	m^3
Time	t	s
Velocity	v	m/s
Angular velocity	ω	rad/s
Acceleration	a	m/s^2
(of free fall)	g	m/s^2
Angular acceleration	α	rad/s^2
Mechanical		
Force	F	N
Weight	W	N
Mass	m	kg
Density	ρ	kg/m^3
Pressure	p	Pa
Momentum	p	kg·m/s
Torque	T, (M)	N·m
Rotational inertia	I, J	$kg{\cdot}m^2$
Work	W	J
Energy	E, W	J
Efficiency	η	numerical
Stress	σ	N/m^2
Strain	ε	numerical

Quantity	*Symbol*	*Unit*
Thermal		
Temperature, Celsius	t, (θ)	°C
Temperature, absolute	T, (Θ)	K
Heat energy	Q	J
Heat flow rate	Φ, (q)	W
Thermal resistance	R_θ	K/W
Thermal resistivity	ρ_θ	m·K/W
Heat capacity	C_θ	J/K
Specific heat	c	J/K·kg
Electrical		
Charge	Q	C
Field strength	E, (K)	V/m
Electromotive force	V, E	V
Current	I	A
Current density	J, (s)	A/m^2
Resistance	R	Ω
Resistivity, volume	ρ	Ω·m
Conductance, $1/R$	G	S
Conductivity	γ, σ	S/m
Reactance	X	Ω
Susceptance, $-1/X$	B	S
Impedance	Z	Ω
Admittance, $1/Z$	Y	S
Characteristic impedance	Z_0	Ω
Transadmittance	y_{xx}	S
Mutual conductance	g_m	S
Amplification factor	μ	numerical
Quality factor, X_S/R_S	Q	numerical
Dissipation factor, $1/Q$	D	numerical
Phase angle	θ, ϕ	rad
Power	P	W
Reactive "power"	Q, (P_q)	var
Apparent "power"	S, (P_s)	V·A
Power factor	$\cos\phi$, F_p	numerical

Quantity	*Symbol*	*Unit*
Period	T	s
Time constant	τ, (T)	s
Frequency	f, (ν)	Hz
Angular frequency	ω	rad/s
Resonant frequency	f_r	Hz
Critical frequency	f_c	Hz
Wavelength	λ	m
Rise time (10%—90%)	t_r	s
Fall time (90%—10%)	t_f	s
Duty factor	D	numerical
Duration of signal element	τ	s
Signaling speed (baud)	$1/t$	Bd
Bandwidth	B	Hz
Noise figure	F	numerical
Amplification (voltage gain)	A_v	numerical
Amplification (current gain)	A_i	numerical
Gain, power	G	numerical
Feedback ratio	β (B)	numerical
Attenuation	α	numerical

SI unit prefixes are given in the table below. Centi, deci, deka, and hecto are to be avoided where possible. Pronounce giga as in *jig*, kilo as in *kill*, nano as in *Nancy*, pico as in *peek*, and peta as in *pet*.

SI Unit Prefixes

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

4.3 UNIT CONVERSIONS

Conversion factors for converting various units to other commensurate units are given in the table that begins on the following page. Conversions are listed alphabetically according to the general name of the quantity involved—*acceleration* first, *volume* last. A list of miscellaneous conversions, plus a table of Fahrenheit-to-Celsius conversions appears at the end of the main table.

- The first conversion given for each unit is to the basic SI (system international) unit in the mksA (meter-kilogram-second-ampere) system. This is the internationally preferred unit, which should be used wherever possible.

- Boldface conversion numbers are exact. Other factors are given to four-digit precision in the interest of practicality.

- If the desired conversion is not listed, try looking up the reverse conversion. To convert from the unit on the right to the unit listed at the left, *divide* by the factor given.

- If a direct conversion does not appear in the table, multiply by the factor given with the known unit and divide by the factor given with the unknown unit. The process may be represented as *unit A* → SI → *unit B*. As an example, we convert 40 biblical cubits to feet:

$$40 \text{ cubits} \times 0.4437 \text{ m/cubit} \div 0.3048 \text{ m/ft}$$

$$= 58.23 \text{ ft}$$

- To convert compound units not listed, convert each unit separately. All units except one will have the numerical coefficient 1. As an example, we convert a fuel efficiency of 23 km/liter to miles per gallon.

$$\frac{23 \text{ km}}{1 \text{ L}} = \frac{23 \times 1000 \text{ m}}{1 \times 10^{-3} \text{ m}^3} = \frac{(2300 \div 1609) \text{ mi}}{(10^{-3} \div 3.785 \times 10^{-3}) \text{ gal}}$$

(given units) (SI units) (convert to desired units)

$$= 54.1 \text{ mi/gal}$$

Unit Conversions

Boldface numbers are exact. Others accurate to 4 digits.

To convert from	*to*	*Multiply by*
Acceleration		
ft/s^2	m/s^2	**0.3048**
	g (earth grav)	0.03108
	$in./s^2$	**12**
earth gravity, *g*	m/s^2	9.807
	ft/s^2	32.17
	$in./s^2$	386.0
$in./sec^2$	m/s^2	**0.0254**
	ft/s^2	0.08333
	g (earth grav)	2.590×10^{-3}
m/sec^2	ft/s^2	3.281
	g (earth grav)	0.1020
	$in./s^2$	39.37
Angle		
degree	rad	0.01745
	gradient	1.111
	minute	**60**
	second	**3600**
gradient	rad	0.01571
	degree	**0.9**
	minute	**54**
	second	**3240**
minute	rad	2.909×10^{-4}
	degree	0.01666
	gradient	0.01852
	second	**60**
radian	degree	57.296
	gradient	63.66
	minute	3438
	second	2.063×10^{5}
second	rad	4.848×10^{-6}
	degree	2.778×10^{-4}
	gradient	3.086×10^{-4}
	minute	0.01666

To convert from	*to*	*Multiply by*
Area		
acre	m^2	4047
	ft^2	**43 560**
	hectare	0.4047
	$mile^2$	1.5625×10^{-3}
	$yard^2$	4840
ft^2	m^2	0.09290
	acre	2.296×10^{-5}
	hectare	9.291×10^{-6}
	$in.^2$	**144**
	$mile^2$	3.587×10^{-8}
	$yard^2$	0.1111
hectare	m^2	**10 000**
	acre	2.471
	ft^2	107 630
	$mile^2$	3.861×10^{-3}
	$yard^2$	11 960
$mile^2$	m^2	2.590×10^{6}
	acre	**640**
	ft^2	$\mathbf{2.78784 \times 10^{6}}$
	hectare	259.0
	$yard^2$	$\mathbf{3.0976 \times 10^{6}}$
$yard^2$	m^2	0.8361
	acre	2.066×10^{-4}
	ft^2	**9**
	hectare	8.361×10^{-5}
	$mile^2$	3.228×10^{-7}
barn	m^2	$\mathbf{10^{-28}}$
circular mil	m^2	5.067×10^{-10}
	cm^2	5.067×10^{-6}
	$in.^2$	7.854×10^{-7}
	mm^2	5.067×10^{-4}
cm^2	m^2	**0.0001**
	circular mil	1.974×10^{5}
	$in.^2$	0.1550
	mm^2	**100**

To convert from	*to*	*Multiply by*
in.^{2}	m^2	**6.4516×10^{-4}**
	cm^2	**6.4516**
	mm^2	**645.16**
mm^2	m^2	**10^{-6}**
Density		
g/cm^3	kg/m^3	**1000**
	lb/ft^3	**62.43**
	lb/in.^{3}	0.03613
	lb/gal	8.345
kg/m^3	g/cm^3	**0.001**
	lb/ft^3	0.06243
	lb/in.^{3}	3.613×10^{-5}
	lb/gal	8.345×10^{-3}
lb/ft^3	kg/m^3	16.02
	g/cm^3	0.01602
	lb/in.^{3}	5.788×10^{-4}
	lb/gal	0.1337
lb/in.^{3}	kg/m^3	2.768×10^4
	g/cm^3	27.68
	lb/ft^3	**1728**
	lb/gal	231.0
lb/gal	kg/m^3	119.8
	g/cm^3	0.1198
	lb/ft^3	7.481
	lb/in.^{3}	4.328×10^{-3}
Electrical and Magnetic		
ampere·turn	gilbert	1.257
ampere/meter	oersted	0.01257
coulomb	faraday	1.036×10^{-5}
decibel	neper	0.1151
faraday	coulomb	9.652×10^4
gauss	tesla	**10^{-4}**
gilbert	ampere·turns	0.7958
maxwell (line)	webber	**10^{-8}**

To convert from	*to*	*Multiply by*
oersted	ampere/meter	79.58
unit pole	webber	1.257×10^{-7}
webber	maxwell	$\mathbf{10^{8}}$
webber	unit pole	7.957×10^{6}
Ω·cm	Ω·m	**0.01**
Ω·cirmil/ft	Ω·m	1.662×10^{-9}
Ω·m	Ω·cirmil/ft	6.017×10^{8}
Ω·mm^2/m	Ω·m	$\mathbf{10^{-6}}$
Energy		
British Thermal Unit	joule, J	1055
(BTU)	calorie	252.0
	erg	1.055×10^{10}
	ft·lb	777.7
	ft·poundal	25 020
	kilocalorie	0.2520
	kW·hr	2.928×10^{-4}
	W·s	1054
calorie	joule, J	4.184
	BTU	3.968×10^{-3}
	electron volt	2.612×10^{19}
	erg	4.184×10^{7}
	ft·lb	3.086
	kilocalorie	**0.001**
	kW·hr	1.162×10^{-6}
	W·s	4.184
electron volt	joule, J	1.602×10^{-19}
	calorie	3.828×10^{-20}
	erg	1.602×10^{-12}
	W·s	1.602×10^{-19}
erg	joule, J	$\mathbf{10^{-7}}$
	BTU	9.484×10^{-11}
	calorie	2.390×10^{-8}
	electron volt	6.242×10^{11}
	ft·lb	7.375×10^{-8}
	kW·hr	2.778×10^{-14}
	W·s	$\mathbf{10^{-7}}$

To convert from	*to*	*Multiply by*
ft·lb	joule, J	1.356
	BTU	1.284×10^{-3}
	calorie	0.3236
	erg	1.356×10^{7}
	ft·poundal	32.17
	kilocalorie	3.236×10^{-4}
	kW·hr	3.767×10^{-7}
	W·s	1.356
ft·poundal	joule, J	0.04214
	ft·lb	0.03108
kilocalorie	joule, J	4184
	BTU	3.968
	calorie	**1000**
kW·hr	joule, J	$\mathbf{3.6 \times 10^{6}}$
	BTU	3409
	calorie	8.592×10^{5}
	electron volt	2.247×10^{25}
	erg	$\mathbf{3.6 \times 10^{13}}$
	ft·lb	2.655×10^{6}
	kilocalorie	860.5
Force		
dyne	newton, N	$\mathbf{10^{-5}}$
	kg-force	1.020×10^{-6}
	ounce-force	3.597×10^{-5}
	pound-force	2.248×10^{-6}
	poundal	7.236×10^{-5}
kg-force	newton, N	9.807
	dyne	9.807×10^{5}
	ounce-force	35.28
	pound-force	2.205
	poundal	70.94
ounce-force	newton, N	0.2780
	dyne	2.780×10^{4}
	kg-force	0.02835
	pound-force	**0.0625**
	poundal	2.011

To convert from	*to*	*Multiply by*
pound-force	newton, N	4.448
	dyne	4.448×10^{5}
	kg-force	0.4536
	ounce-force	**16**
	poundal	32.17
poundal	newton, N	0.1382
	dyne	13 820
	kg-force	0.01409
	ounce-force	0.4973
	pound-force	0.03108
Length		
angstrom	meter, m	$\mathbf{10^{-10}}$
	inch	3.937×10^{-9}
	microinch	3.937×10^{-3}
	mm	$\mathbf{10^{-7}}$
astronomical unit	m	1.496×10^{11}
	light-year	1.581×10^{-5}
	miles	9.298×10^{7}
	parsec	4.848×10^{-6}
cable	m	219.5
	foot	**720**
chain	m	20.12
	fathom	**11**
	foot	**66**
	furlong	**0.1**
	league	4.167×10^{-3}
	mile	**0.0125**
	rod	**4**
	yard	**22**
cubit, English	m	0.4572
	inch	18
cubit, biblical	m	0.5537
	inch	21.8

To convert from	*to*	*Multiply by*
fathom	m	1.829
	foot	**6**
foot	m	**0.3048**
	chain	0.01515
	cubit, English	0.6667
	cubit, biblical	0.5505
	fathom	0.1667
	furlong	1.515×10^{-3}
	hand	**3**
	inch	**12**
	league	6.313×10^{-5}
	mile	1.894×10^{-4}
	mile, nautical	1.646×10^{-4}
	rod	0.06061
	span	1.333
	yard	0.3333
furlong	m	201.2
	foot	**660**
hand	m	**0.1016**
	inch	**4**
	foot	0.3333
inch	m	0.0254
	foot	0.08333
	hand	**0.25**
	mil	**1000**
	pica	6.022 (0r **6**)
	point	72.26 (or **72**)
league	m	4828
	foot	**15 840**
	miles	**3**
league, nautical	m	5556
	foot	**18 230**
	miles, nautical	**3**
light-year	m	9.461×10^{15}
	mile	5.878×10^{12}
	parsec	0.3067

To convert from	*to*	*Multiply by*
microinch	m	**2.54×10^{-8}**
	inch	**10^{-6}**
	micron	**0.0254**
	mil	**0.001**
	mm	**2.54×10^{-5}**
micron	m	**10^{-6}**
	inch	3.937×10^{-5}
	microinch	39.37
	mil	0.03937
	mm	**0.001**
mil	m	**2.54×10^{-5}**
	inch	**0.001**
	microinch	**1000**
	micron	**25.4**
	mm	**0.0254**
mile	m	1609
	foot	**5280**
	furlong	**8**
	km	1.609
	league	0.3333
	light-year	1.701×10^{-13}
	mile, nautical	0.8689
	rod	**320**
	yard	**1760**
mile, nautical	m	1852
	foot	6076
	km	1.852
	league, nautical	0.3333
	mile	1.151
parsec	m	3.084×10^{16}
	light-year	3.261
	mile	1.916×10^{13}

To convert from	*to*	*Multiply by*
pica	m	4.218×10^{-3}
	inch	0.1667
	mm	4.218
	point	**12**
point	m	3.515×10^{-4}
	inch	0.01388
	mm	0.3515
	pica	0.8333
rod	m	5.029
	chain	**0.25**
	fathom	**2.75**
	foot	**16.5**
	furlong	**0.025**
	league	1.042×10^{-3}
	mile	3.126×10^{-3}
	yard	**5.5**
yard	m	**0.9144**
	chain	0.04545
	fathom	**0.5**
	foot	**3**
	furlong	4.545×10^{-3}
	inch	**36**
	league	1.894×10^{-4}
	mile	5.683×10^{-4}
	mile, nautical	4.937×10^{-4}
	rod	0.1818
Light (source)		
candle	lumen/steradian	**1**
	candela	**1**
candlepower	lumen	12.57
lumen	candlepower	0.07958
lumen	watt	1.5×10^{-3}
Light (illumination)		
ft·candle	lumen/ft^2	**1**
	lumen/m^2	10.76
	lux	10.76

To convert from	*to*	*Multiply by*
lumen/m^2	lux	**1**
	ft·candle	0.09290
lumen/ft^2	ft·lambert	**1**
	ft·candle	**1**
	lumen/m^2	10.76
lux	ft·candle	0.09290
Mass		
carat (jeweler's)	kg	$\mathbf{2 \times 10^{-4}}$
	grain	3.086
	gram	**0.2**
dram, avp	kg	1.772×10^{-3}
	grain	27.34
	gram	1.772
	ounce, avp	**0.0625**
grain	kg	6.480×10^{-5}
	carat	0.3240
	dram, avp	0.03657
	ounce, avp	2.29×10^{-3}
gram	kg	$\mathbf{10^{-3}}$
	carat	**5**
	dram, avp	0.5644
	grain	15.43
	pound	2.205×10^{-3}
kg (kilogram)	ounce	35.28
	pound	2.205
	slug	0.06852
	stone	0.1575
	ton, short	1.102×10^{-3}
	tonne, metric	$\mathbf{10^{-3}}$
ounce, avp	kg	0.02835
	carat	141.8
	dram	**16**
	grain	437.5
	gram	28.35
	ounce, troy or apoth	0.9115
	pound	**0.0625**

To convert from	*to*	*Multiply by*
ounce, troy or apoth	ounce, avp	1.097
pennyweight	kg	1.555×10^{-3}
	g	1.555
	ounce	0.05486
	pound	3.429×10^{-3}
pound	kg	0.4536
	ounce	**16**
	poundal	32.17
	stone	0.07143
	slug	0.03108
	ton, long	4.464×10^{-4}
	ton, short	$\mathbf{5 \times 10^{-4}}$
	tonne, metric	4.535×10^{-4}
poundal	kg	0.01410
	pound	0.03108
slug	kg	**14.59**
	pound	32.17
stone	kg	6.350
	pound	**14**
ton, long	kg	1016
	pound	**2240**
ton, short	kg	907.2
	pound	**2000**
tonne, metric	kg	**1000**
	pound	2205
Power		
BTU/hr	watt	0.2929
	BTU/min	0.01667
	cal/hr	252.0
	cal/min	4.200
	cal/sec	0.0700
	erg/sec	2.929×10^{6}
	ft·lb/sec	0.2160
	horsepower	3.929×10^{-4}
	ton, refrig	8.333×10^{-5}

To convert from	*to*	*Multiply by*
cal/sec	watt	**4.184**
	BTU/hr	14.29
	erg/sec	4.184×10^7
	ft·lb/sec	3.085
	horsepower	5.609×10^{-3}
	ton, refrig	1.191×10^{-3}
erg/sec	watt	$\mathbf{10^{-7}}$
ft·lb/sec	watt	1.356
	BTU/hr	4.626
	horsepower	1.818×10^{-3}
	ton, refrig	3.856×10^{-4}
horsepower	watt	**746**
	BTU/hr	2547
	cal/sec	178.3
	ft·lb/sec	**550**
	ft·lb/min	**33 000**
	ton, refrig	0.2121
ton, refrig	watt	3517
	BTU/hr	**12 000**
	horsepower	4.714
watt	BTU/hr	3.415
	cal/min	14.34
	erg/sec	$\mathbf{10^{7}}$
	ft·lb/sec	0.7375
	ft·lb/min	44.25
	horsepower	1.340×10^{-3}
	ton, refrig	2.846×10^{-4}
Pressure		
atmosphere	pascal, Pa	1.013×10^5
bar	pascal	$\mathbf{10^{5}}$
cm of mercury	pascal	1333
dyne/cm^2	pascal	**0.1**
gram/cm^2	pascal	98.07
	lb/in.^{2}	0.01422

To convert from	to	Multiply by
inch of mercury	pascal	3386
lb/in.^{2} (psi)	pascal	6895
	gram/cm^2	70.31
pascal	cm Hg	7.502×10^{-4}
	gram/.cm^2	0.01020
	lb/in.^{2}	70.32
torr (mm Hg)	pascal	133.3
Temperature		
°C → K	$t_K = t_{°C} + 273.15°$	
°C → F	$t_F = 1.8\, t_{°C} + 32$	
°F → K	$t_{°K} = (t_{°F} + 459.7°) \div 1.8$	
°F → °C	$t_C = (t_{°F} - 32°) \div 1.8$	
°F → °R	$t_R = t_{°F} + 459.7°$	
Thermal capacity		
BTU/lb·°F	J/kg·K	4187
cal/kg·K	J/kg·K	4.190
J/kg·K	BTU/lb·°F	2.388×10^{-4}
	cal/kg·K	0.2387
Thermal conductivity		
BTU·in./hr·ft^2·°F	J/kg·K	0.1442
J/kg·K	BTU·in./hr·ft^2·°F	6.935
(*R* insulating value is the reciprocal of thermal conductivity in BTU·in./hr·ft^2·°F.)		
Torque		
dyne·cm	N·m	**10^{-7}**
	kg-force·m	1.020×10^{-8}
	oz-force·in.	1.416×10^{-5}
	lb-force·ft	7.375×10^{-8}
kg-force·m	N·m	9.807
	dyne·cm	9.807×10^{-7}
	oz-force·in.	1389
	lb-force·ft	7.23
lb-force·ft	N·m	1.356
	dyne·cm	1.356×10^{-7}
	kg-force·m	0.1383
	oz-force·in.	**192**

To convert from	*to*	*Multiply by*
N·m	dyne·cm	**10^7**
	kg-force·m	0.1020
	oz-force·in.	141.6
	lb-force·ft	0.7375
oz-force·in.	N·m	7.062×10^{-3}
	dyne·cm	7.062×10^{4}
	kg-force·m	7.201×10^{-4}
	lb-force·ft	5.208×10^{-3}
Velocity		
c (light)	m/s	2.998×10^{8}
	ft/s	9.836×10^{8}
	mi/hr	6.706×10^{8}
ft/min	m/s	5.080×10^{-3}
	ft/s	0.01667
	in./s	**0.2**
	km/hr	0.01829
	mi/hr	0.01136
ft/s	m/s	**0.3048**
	ft/min	**60**
	in./s	**12**
	km/hr	1.097
	knot	0.5922
	mach number	9.200×10^{-4}
	mi/hr	0.6818
in./s	m/s	**0.0254**
	mi/hr	0.05682
km/h	m/s	0.2778
	ft/s	0.9114
	knot	0.5400
	mi/hr	0.6214
knot	m/s	0.5144
	ft/s	1.688
	km/hr	1.852
	mi/hr	1.151

To convert from	*to*	*Multiply by*
mach number	m/s	331.3
	ft/s	1087
	km/hr	1193
	mi/hr	741.2
mi/h	m/s	**0.44704**
	ft/s	1.467
	km/h	1.609
	knot	0.8690
mi/s	m/s	1609
	c (light)	5.367×10^{-6}
	km/s	1.609
	mi/min	**60**
Volume		
acre·foot	m^3	1233
	barrel, 42-g oil	7758
	ft^3	43 560
	gallon	3.259×10^5
	yd^3	1613
barrel, 42-g oil	m^3	0.1590
	ft^3	5.614
	gallon	**42**
	liter	159.0
board·foot	m^3	2.360×10^{-3}
	ft^3	0.08333
bushel	m^3	0.3524
	ft^3	1.244
	liter	35.24
	peck	**4**
	quart, dry	**32**
	yd^3	0.04607
cord (wood)	m^3	3.625
	ft^3	**128**

To convert from	to	Multiply by
cup	m^3	2.366×10^{-4}
	fl oz	**8**
	gallon	**0.0625**
	gill	**2**
	liter	0.2366
	pint	**0.5**
	quart	**0.25**
	tablespoon	**16**
	teaspoon	**48**
ft^3	m^3	0.02832
	acre·ft	2.296×10^{-5}
	barrel, 42-g oil	0.1781
	board·ft	**12**
	bushel	0.8036
	cord	7.812×10^{-3}
	cup	119.7
	gallon	7.481
	$in.^3$	**1728**
	liter	28.32
	peck	3.215
	perch (stone)	0.04040
	$yard^3$	0.03704
gallon, US	m^3	3.785×10^{-3}
	acre·ft	3.069×10^{-6}
	bushel	0.1074
	barrel, 42-g oil	0.02381
	cup	**16**
	ft^3	0.1337
	liter	3.785
	peck	0.4296
	pint	**8**
	quart	**4**
	$yard^3$	4.950×10^{-3}
gallon, Brit.	m^3	4.546×10^{-3}
	gallon, US	1.201

To convert from	*to*	*Multiply by*
in.^{3}	m^3	1.639×10^{-5}
	cup	0.06927
	gallon	4.333×10^{-3}
	liter	0.01639
	ounce, fl	0.5541
jigger	ounce, fl	**1.5**
liter (L)	m^3	$\mathbf{10^{-3}}$
	barrel, 42-g oil	6.289×10^{-3}
	bushel	0.02838
	cup	4.227
	gallon	0.2642
	in.^{3}	61.01
	ounce, fl	33.82
	pint	2.113
	quart	1.057
	tablespoon	67.61
m^3 (cubic meter)	acre·ft	8.110×10^{-4}
	barrel, 42-g oil	6.289
	board-ft	423.7
	bushel	28.38
	cord	0.2759
	cup	4227
	ft^3	35.31
	gallon	264.2
	liter	**1000**
	perch (stone)	1.427
	yard^3	1.308
milliliter (ml)	m^3	$\mathbf{10^{-6}}$
	inch^3	0.06101
	liter	**0.001**
	ounce, fl	0.03382
	teaspoon	0.2029
ounce, fluid	m^3	2.957×10^{-5}
	cup	**0.125**
	gallon	7.812×10^{-3}
	in.^{3}	1.804

To convert from	*to*	*Multiply by*
	liter	0.02957
	pint	**0.0625**
	quart	**0.03125**
	tablespoon	**2**
	teaspoon	**6**
peck, US, dry	m^3	8.810×10^{-3}
	barrel, 42-g oil	0.05541
	bushel	**0.25**
	cup, liq	37.24
	ft^3	0.3111
	gallon, liq	2.327
	liter	8.810
	quart, dry	**8**
	quart, liq	9.309
perch (stone)	m^3	0.7004
	ft^3	24.75
pint, liquid	m^3	4.732×10^{-4}
	cup	**2**
	gallon	**0.125**
	$in.^3$	28.87
	liter	0.4732
	ounce, fl	**16**
	quart	**0.5**
	tablespoon	**32**
	teaspoon	**96**
quart, dry	m^3	1.101×10^{-3}
quart, liquid	m^3	9.464×10^{-4}
	cup	**4**
	gallon	**0.25**
	$in.^3$	57.74
	liter	0.9464
	ounce	**32**
	pint	**2**
	quart, dry	0.8594
	tablespoon	**64**
	teaspoon	**192**

To convert from	*to*	*Multiply by*
tablespoon	m^3	1.479×10^{-5}
	cup	**0.0625**
	gallon	3.906×10^{-3}
	$in.^3$	0.9024
	liter	0.01479
	ounce, fl	**0.5**
	pint	**0.03125**
	quart	0.01562
	teaspoon	**3**
teaspoon	m^3	4.929×10^{-6}
	cup	0.02083
	$in.^3$	0.3008
	milliliter	4.929
	ounce, fl	0.1667
	pint	0.01042
	tablespoon	0.3333
yd^3	m^3	0.7646
	acre·ft	6.199×10^{-4}
	barrel, 42-g oil	4.809
	bushel	21.70
	cord	0.2109
	ft^3	**27**
	gallon	202.0
	$inch^3$	**46 656**
	liter	764.6
	peck	86.79
	quart, liq	807.9

Miscellaneous Conversions

Fuel consumption: 1 mi/gal = 0.425 km/liter
1 mi/gal = 222.2 liter/100 km

To convert mi/gal and liters/100 km, as used in Europe:

mi/gal × liters/100 km = 235.3

One carat of gold = 41.67 mg/g. Thus 24 kt = pure gold.

Fahrenheit - Celsius Conversions

°C	°F	°C	°F	°C	°F
–100	–148	0	32	36	97
–90	–130	1	34	37	99
–80	–112	2	36	38	100
–70	–94	3	37	39	102
–60	–76	4	39	40	104
–55	–67	5	41	41	106
–50	–58	6	43	42	108
–45	–49	7	45	43	109
–40	–40	8	46	44	111
–35	–31	9	48	45	113
–30	–22	10	50	46	115
–25	–13	11	52	47	117
–24	–11	12	54	48	118
–23	–9	13	55	49	120
–22	–8	14	57	50	122
–21	–6	15	59	55	131
–20	–4	16	61	60	140
–19	–2	17	63	65	149
–18	–0.4	18	64	70	158
–17	1	19	66	75	167
–16	3	20	68	80	176
–15	5	21	70	85	185
–14	7	22	72	90	194
–13	9	23	73	95	203
–12	10	24	75	100	212
–11	12	25	77	125	257
–10	14	26	79	150	302
–9	16	27	81	175	347
–8	18	28	82	200	392
–7	19	29	84	225	437
–6	21	30	86	250	482
–5	23	31	88	275	527
–4	25	32	90	300	572
–3	27	33	91	325	617
–2	28	34	93	350	662
–1	30	35	95	400	752

4.4 PHYSICAL PROPERTIES AND CONSTANTS

Selected physical constants

Length of a 1-s pendulum at sea level	= 0.994 m
Solar radiation intensity at earth distance	= 1.35 kW/m^2
Mean radius of earth	= 6370 km
Mass of earth	= 5.983×10^{24} kg
Earth gravity (g)	= 9.81 m/s^2
Gravitational constant (G)	= 6.670×10^{-11} $N{\cdot}m^2/kg^2$
Standard atmospheric pressure	= 1.013×10^5 N/m^2
Boltzmann's constant (k)	= 1.381×10^{-23} J/K
Planck's constant (h)	= 6.626×10^{-34} J·s
Avogadro's number (N_A)	= 6.023×10^{23} atoms/mole
Permeability of vacuum (μ_0)	= $4\pi \times 10^{-7}$ H/m
Permittivity of vacuum (ε)	= 8.854×10^{-12} F/m
Electron charge (e)	= 1.602×10^{-19} C
Charge-to-mass ratio of the electron	= 1.759×10^{11} C/kg
Atomic mass unit (C^{12} = 12 amu)	= 1.6605×10^{-27} kg
Electron mass	= 5.486×10^{-4} amu
Proton mass	= 1.00728 amu
Neutron mass	= 1.00867 amu
Alpha particle mass	= 4.00151 amu
Diameter of hydrogen atom	= 1.06×10^{-10} m
Velocity of electromagnetic waves (c_0)	= 2.998×10^8 m/s
Velocity of sound in air (14.7 lb/in.^{2}, 0 °C)	= 331.4 m/s
Velocity of sound in water	= 1420 m/s
Velocity of sound in steel	= 5103 m/s

Sound intensity is measured in decibels, with 10^{-12} W/m^2 defined as 0 dB. The lower limit of audibility varies with individuals, but is normally within a few dB of 0 dB. The ear is most sensitive at about 3 kHz. Sensitivity at 300 Hz is down by about 20 dB.

15 dB	whisper	70 dB	truck engine
30 dB	office background	85 dB	jackhammer
55 dB	average conversation	110 dB	jet engine

Air pressure (atm) vs. elevation (km)

(km)	0	0.5	1.0	2.0	3.0	5.0	10	20
(atm)	1.00	0.94	0.89	0.78	0.69	0.54	0.26	0.056

Coefficients of sliding friction, $F_{parallel} / F_{normal}$
for selected materials (numerical)

Rubber on dry pavement	0.75
Rubber on wet pavement	0.50
Wood on hardwood floor	0.25
Steel on steel (dry)	0.20
Steel on steel (oiled)	0.06
Steel runners on ice	0.04

Density at 0 °C and standard pressure
for selected materials (kg/m^3)

Gold	19 300	Mercury	13 600
Lead	11 400	Water	1 000
Copper	8 890	Seawater	1 025
Steel	7 830	Ice	910
Aluminum	2 700	Gasoline	690
Magnesium	1 741	Propane	2.02
Cork	224	Carbon dioxide	1.96
Pine wood	430	Air	1.29
Oak wood	750	Helium	0.18
Birch wood	640	Hydrogen	0.09

Young's modulus Y (stress/strain) and ultimate strength (s_x) for selected metals

Material	Y ($N/m^2 \times 10^{10}$)	σ_x ($N/m^2 \times 10^8$)
Aluminum	7.0	1.4
Copper	12.5	2.4
Cast iron	9.1	2.9
Mild steel	17.2	4.1
Spring steel	—	13.8
Tungsten	35	41
Magnesium	4.2	1.9

Thermal coefficients of expansion ($1/K \times 10^{-6}$)

Linear		*Volume*	
Aluminum	24	Alcohol	1220
Brass	18	Gasoline	1080
Copper	17	Water at 20 °C	207
Glass	8	Mercury	182
Glass (Pyrex)	3		
Steel	11		
Magnesium	28		

Thermal conductivity (W/m·K)

Silver	415	Sand, concrete	1.8
Copper	381	Glass	0.78
Aluminum	213	Brick	0.72
Steel	50	Wood (fir)	0.11
Lead	35	Cork board	0.037
Ice	2.2	Fiberglass insulation	0.036

Heating values of fuels ($J/kg \times 10^{6}$)

Hydrogen	142	Fuel oil	45
Natural gas	55	Coal (hard)	33
Gasoline	47	Wood (average)	15
Kerosene	46		

Melting and boiling points at standard pressure (K)

Substance	*Melting*	*Boiling*
Helium	0.094	4.3
Nitrogen	63.2	77.1
Carbon dioxide	216.5	213.2
Ammonia	198.7	239.8
Alcohol, ethyl	143.2	350.6
Water	273.2	373.2
Tin	505	2530
Lead	600	1890
Copper	1360	2570
Iron	1810	3260

Heat capacities of various substances (J/kg·K)

Water	4190	Air	1010	Steel	482
Ice	2100	Aluminum	922	Copper	390
Steam	2010	Dry earth	840	Lead	126

Heats of fusion and vaporization (J/kg $\times 10^6$)

Substance	*Fusion*	*Vaporization*
Water	0.335	2.26
Ammonia	0.452	1.37
Alcohol	0.104	0.855

Weight of water vapor in saturated air (kg/kg)

°C	kg/kg	°C	kg/kg
10	0.0076	35	0.0370
15	0.0107	40	0.0490
20	0.0149	45	0.0653
25	0.0205	50	0.0868
30	0.0279	55	0.1142

Greek Alphabet

Α, α	Alpha (AYL-fa)	Ν, ν	Nu (New)
Β, β	Beta (BAY-tah)	Ξ, ξ	Xi (Zigh)
Γ, γ	Gamma	Ο, ο	Omicron
Δ, δ	Delta	Π, π	Pi
Ε, ε	Epsilon (EP-sah-lon)	Ρ, ρ	Rho
Ζ, ζ	Zeta	Σ, σ	Sigma
Η, η	Eta	Τ, τ	Tau (Taow)
Θ, θ	Theta (THAY-tah)	Υ, υ	Upsilon
Ι, ι	Iota	Φ, φ	Phi
Κ,κ	Kappa	Χ, χ	Chi
Λ, λ	Lamda	Ψ, ψ	Psi (Sigh)
Μ, μ	Mu (Mew)	Ω, ω	Omega