Appendices

Contents

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APPENDIX A

Conversion Factors

Table A.1 ***Names and Symbols of SI Units[1]***

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	
Luminous intensity	Candela	cd	
Amount of substance	Mole	mol	
SI-DERIVED 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	$kg \cdot m/s^2$
Pressure (mechanical stress)	Pascal	Pa	N/m^2
Kinematic viscosity	Square meter per second	m^2/s	
Dynamic viscosity	Newton-second per square meter	$N \cdot s/m^2$	
Work, energy, quantity of heat	Joule	J	$N \cdot m$
Power	Watt	W	J/s
Quantity of electricity	Coulomb	C	$A \cdot s$
Potential difference, electromotive force	Volt	V	W/A
Electric field strength	Volt per meter	V/m	
Electric resistance	Ohm	Ω	V/A
Capacitance	Farad	F	$A \cdot s/V$
Magnetic flux	Weber	Wb	$V \cdot s$
Inductance	Henry	H	$V \cdot s/A$
Magnetic flux density	Tesla	T	Wb/m^2
Magnetic field strength	Ampere per meter	A/m	
Magnetomotive force	Ampere	A	
Luminous flux	Lumen	lm	$cd \cdot sr$
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	$J/(kg \cdot K)$	
Thermal conductivity	Watt per meter kelvin	$W/(m \cdot K)$	
Radiant intensity	Watt per steradian	W/sr	
Activity (or a radioactive source)	1 per second	s^{-1}	
SI SUPPLEMENTARY UNITS			
Plane angle	Radian	rad	
Solid angle	Steradian	sr	

Table A.2 ***Definitions of SI Units***[1]

Meter (m)	The *meter* is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels 2 p_{10} and 5 d_s of the krypton-86 atom.
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, which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in a 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.
Candela (cd)	The *candela* is the luminous intensity, in the perpendicular direction, of a surface of 1/600 000 square meter of a blackbody at the temperature of freezing platinum under a pressure of 101 325 newtons per square meter.
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 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.
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.
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.
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.
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.

The names of multiples and submultiples of SI units can be formed by application of the prefixes in Table A.3. The International Organization for Standardization (ISO) recommends the following rules for the use of SI prefixes:

1. Prefix symbols are printed in roman (upright) type without spacing between the prefix symbol and the unit symbol.
2. An exponent affixed to a symbol containing a prefix indicates that the multiple or submultiple of the unit is raised to the power expressed by the exponent.

Example: $1\ \mathrm{cm}^3 = 10^{-6}\ \mathrm{m}^3$
$1\ \mathrm{cm}^{-1} = 10^{2}\ \mathrm{m}^{-1}$

3. Compound prefixes, formed by the juxtaposition of two or more SI prefixes, are not to be used.

Example: 1 nm *but not:* 1 mμm

ISO has issued additional recommendations with the aim of securing uniformity in the use of units. According to these recommendations,

1. The product of two or more units is preferably indicated by a dot. The dot may be dispensed with when there is no risk of confusion with another unit symbol.

Example: N·m or Nm *but not:* mN

2. A solidus (oblique stroke, /), a horizontal line, or negative powers may be used to express a derived unit formed from two others by division.

Example: m/s, $\frac{\mathrm{m}}{\mathrm{s}}$, or $\mathrm{m\cdot s^{-1}}$

3. The solidus must not be repeated on the same line unless ambiguity is avoided by parentheses. In complicated cases negative powers or parentheses should be used.

Example: $\mathrm{m/s^2}$ or $\mathrm{m\cdot s^{-2}}$ *but not:* m/s/s

$\mathrm{m\cdot kg/(s^3\cdot A)}$ or $\mathrm{m\cdot kg\cdot s^{-3}\cdot A^{-1}}$

but not: $\mathrm{m\cdot kg/s^3/A}$

Table A.3 ***SI Prefixes***[1]

Factor by Which Unit Is Multiplied	Prefix	Symbol
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{2}	Hecto	h
10	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

Table A.4 lists physical constants from the work of B. N. Taylor, W. H. Parker, and D. N. Langenberg.[2] Their least-squares adjustment of values of the constants depends strongly on a highly accurate (2.4 ppm) determination of e/h from the ac Josephson effect in superconductors, and is believed to be more accurate than the 1963 adjustment, which appears to suffer from the use of an incorrect value of the fine structure constant as an input datum. See also *NBS Special Publication 344,* issued March 1971.

Table A.4 ***Physical Constants***[2]

Quantity	Symbol	Value	Error (ppm)	Prefix	Unit
Speed of light in vacuum	c	2. 997 925 0	0.33	$\times 10^{8}$	$m \cdot s^{-1}$
Gravitational constant	G	6. 673 2	460	10^{-11}	$N \cdot m^{2} \cdot kg^{-2}$
Avogadro constant	N_A	6. 022 169	6.6	10^{26}	$kmol^{-1}$
Boltzmann constant	k	1. 380 622	43	10^{-23}	$J \cdot K^{-1}$
Gas constant	R	8. 314 34	42	10^{3}	$J \cdot kmol^{-1} \cdot K^{-1}$
Volume of ideal gas, standard conditions	V_0	2. 241 36	—	10^{1}	$m^{3} \cdot kmol^{-1}$
Farady constant	F	9. 648 670	5.5	10^{7}	$C \cdot kmol^{-1}$
Unified atomic mass unit	u	1. 660 531	6.6	10^{-27}	kg
Planck constant	h	6. 626 196	7.6	10^{-34}	$J \cdot s$
	$h/2\pi$	1. 054 591 9	7.6	10^{-34}	$J \cdot s$
Electron charge	e	1. 602 191 7	4.4	10^{-19}	C
Electron rest mass	m_e	9. 109 558	6.0	10^{-31}	kg
		5. 485 930	6.2	10^{-4}	u
Proton rest mass	m_p	1. 672 614	6.6	10^{-27}	kg
		1. 007 276 61	0.08	—	u
Neutron rest mass	m_n	1. 674 920	6.6	10^{-27}	kg
		1. 008 665 20	0.10	—	u
Electron charge to mass ratio	e/m_e	1. 758 802 8	3.1	10^{11}	$C \cdot kg^{-1}$
Stefan-Boltzmann constant	σ	5. 669 61	170	10^{-8}	$W \cdot m^{-2} \cdot K^{-4}$
First radiation constant	$2\pi hc^2$	3. 741 844	7.6	10^{-16}	$W \cdot m^{2}$
Second radiation constant	hc/k	1. 438 833	43	10^{-2}	$m \cdot K$
Rydberg constant	R_∞	1. 097 373 12	0.10	10^{7}	m^{-1}
Fine structure constant	α	7. 297 351	1.5	10^{-3}	
	α^{-1}	1. 370 360 2	1.5	10^{2}	
Bohr radius	a_0	5. 291 771 5	1.5	10^{-11}	m
Classical electron radius	r_e	2. 817 939	4.6	10^{-15}	m
Compton wavelength of electron	λ_C	2. 426 309 6	3.1	10^{-12}	m
	$\lambda_C/2\pi$	3. 861 592	3.1	10^{-13}	m
Compton wavelength of proton	$\lambda_{C,p}$	1. 321 440 9	6.8	10^{-15}	m
	$\lambda_{C,p}/2\pi$	2. 103 139	6.8	10^{-16}	m
Compton wavelength of neutron	$\lambda_{C,n}$	1. 319 621 7	6.8	10^{-15}	m
	$\lambda_{C,n}/2\pi$	2. 100 243	6.8	10^{-16}	m
Electron magnetic moment	μ_e	9. 284 851	7.0	10^{-24}	$J \cdot T^{-1}$
Proton magnetic moment	μ_p	1. 410 620 3	7.0	10^{-26}	$J \cdot T^{-1}$
Bohr magneton	μ_B	9. 274 096	7.0	10^{-24}	$J \cdot T^{-1}$
Nuclear magneton	μ_n	5. 050 951	10	10^{-27}	$J \cdot T^{-1}$
Gyromagnetic ratio of protons in H_2O	γ'_p	2. 675 127 0	3.1	10^{8}	$rad \cdot s^{-1} T^{-1}$
	$\gamma'_p/2\pi$	4. 257 597	3.1	10^{7}	$Hz \cdot T^{-1}$
Gyromagnetic ratio of protons in H_2O	γ'_p	2. 675 196 5	3.1	10^{8}	$rad \cdot s^{-1} T^{-1}$
Corrected for diamagnetism of H_2O	$\gamma'_p/2\pi$	4. 257 707	3.1	10^{7}	$Hz \cdot T^{-1}$
Magnetic flux quantum	Φ_0	2. 067 853 8	3.3	10^{-15}	Wb
Quantum of circulation	$h/2m_e$	3. 636 947	3.1	10^{-4}	$J \cdot s \cdot kg^{-1}$
	h/m_e	7. 273 894	3.1	10^{-4}	$J \cdot s \cdot kg^{-1}$

Table A.4 ***(Continued)***

Unitless Numerical Ratios	Value	Error (ppm)	Prefix
(c^2) kg/eV	5. 609 538	4.4	10^{35}
(c^2) u/eV	9. 314 812	5.5	10^{8}
u/kg	1. 660 531	6.6	10^{-27}
(c^2) m_c/eV	5. 110 041	3.1	10^{5}
(c^2) m_p/eV	9. 382 592	5.5	10^{8}
(c^2) m_n/eV	9. 395 527	5.5	10^{8}
eV/J	1. 602 191 7	4.4	10^{-19}
(h^{-1}) eV/Hz	2. 417 965 9	3.3	10^{14}
(hc^{-1}) eVm	8. 065 465	3.3	10^{5}
(k^{-1}) eV/K	1. 160 485	42	10^{4}
(hc) $(\text{eVm})^{-1}$	1. 239 854 1	3.3	10^{-6}
(hc) R_∞/J	2. 179 914	7.6	10^{-18}
(hc) R_∞/eV	1. 360 582 6	3.3	10^{1}
(c) R_∞/Hz	3. 289 842 3	0.35	10^{15}
(hc/k) R_∞/K	1. 578 936	43	10^{5}
m_p/m_e	1. 836 109	6.2	10^{3}
μ_e/μ_B	1. 001 159 638 9	0.0031	
μ'_p/μ_B	1. 520 993 12	0.066	10^{-3}
μ_p/μ_B	1. 521 032 64	0.30	10^{-3}
μ'_p/μ_n	2. 792 709	6.2	
μ_p/μ_n	2. 792 782	6.2	

Other Important Constants

π = 33.141 592 653 589
e = 2.718 281 828 459
$\mu_0 = 4\pi \times 10^{-7}$ H/m (exact), permeability of free space
$= 1.256\,637\,061 \times 10^{-6}$ H/m
$\varepsilon_0 = \mu_0^{-1} c^{-2}$ F/m, permittivity of free space
$= 8.854\,185 \times 10^{-12}$ F/m

The following tables express the definitions of miscellaneous units of measure as exact numerical multiples of coherent SI units, and provide multiplying factors for converting numbers and miscellaneous units to corresponding new numbers and SI units.

The first two digits of each numerical entry represents a power of 10. An asterisk following a number expresses an exact definition. For example, the entry –02 2.54* expresses the fact that 1 inch = 2.54×10^{-2} meter, exactly, by definition. Most of the definitions are extracted from National Bureau of Standards (NBS) documents. Numbers not followed by an asterisk are only approximate representations of definitions, or are the results of physical measurements.

The conversion factors are listed alphabetically in Table A.5 and by physical quantity in Table A.6. The listing by physical quantity (Table A.6) includes only relationships that are frequently encountered, and deliberately omits the great multiplicity of combinations of units that are used for more specialized purposes. Conversion factors for combinations of units are easily generated from numbers given in the alphabetical listing (Table A.5) by the technique of direct substitution or by other well-known rules for manipulating units. These rules are adequately discussed in many science and engineering textbooks and are not repeated here.

Table A.5 ***Alphabetical Listing of Conversion Factors***[1]

To Convert from	to	Multiply by
Abampere	Ampere	+01 1.00*
Abcoulomb	Coulomb	+01 1.00*
Abfarad	Farad	+09 1.00*
Abhenry	Henry	−09 1.00*
Abmho	Siemens	+09 1.00*
Abohm	Ohm	−09 1.00*
Abvolt	Volt	−08 1.00*
Acre	Meter^2	+03 4.046 856 422 4*
Angstrom	Meter	−10 1.00*

Table A.5 *(Continued)*

To Convert from	to	Multiply by
Are	Meter^2	+02 1.00*
Astronomical unit (IAU)	Meter	+11 1.496 00
Astronomical unit (radio)	Meter	+11 1.495 978 9
Atmosphere	Newton/meter^2	+05 1.013 25*
Bar	Newton/meter^2	+05 1.00*
Barn	Meter^2	−28 1.00*
Barrel (petroleum, 42 gallons)	Meter^3	−01 1.589 873
Barye	Newton/meter^2	−01 1.00*
Board foot (1' × 1' × 1")	Meter^3	−03 2.359 737 216*
British thermal unit		
IST before 1956	Joule	+03 1.055 04
IST after 1956	Joule	+03 1.055 056
British thermal unit (mean)	Joule	+03 1.055 87
British thermal unit (thermochemical)	Joule	+03 1.054 350
British thermal unit (39°F)	Joule	+03 1.059 67
British thermal unit (60°F)	Joule	+03 1.054 68
Bushel (U.S.)	Meter^3	−02 3.523 907 016 688*
Cable	Meter	+02 2.194 56*
Caliber	Meter	−04 2.54*
Calorie (International Steam Table)	Joule	+00 4.1868
Calorie (mean)	Joule	+00 4.190 02
Calorie (thermochemical)	Joule	+00 4.184*
Calorie (15°C)	Joule	+00 4.185 80
Calorie (20°C)	Joule	+00 4.181 90
Calorie (kilogram, International Steam Table)	Joule	+03 4.1868
Calorie (kilogram, mean)	Joule	+03 4.190 02
Calorie (kilogram, thermochemical)	Joule	+03 4.184*
Carat (metric)	Kilogram	−04 2.00*
Celsius (temperature)	Kelvin	$t_K = t_c + 273.15$
Centimeter of mercury (0°C)	Newton/meter^2	+03 1.333 22
Centimeter of water (4°C)	Newton/meter^2	+01 9.806 38
Chain (engineer or ramden)	Meter	+01 3.048*
Chain (surveyor or gunter)	Meter	+01 2.011 68*
Circular mil	Meter^2	−10 5.067 074 8
Cord	Meter^3	+00 3.624 556 3
Cubit	Meter	−01 4.572*
Cup	Meter^3	−04 2.365 882 365*
Curie	Disintegration/second	+10 3.70*
Day (mean solar)	Second (mean solar)	+04 8.64*
Day (sidereal)	Second (mean solar)	+04 8.616 409 0
Degree (angle)	Radian	−02 1.745 329 251 994 3
Denier (international)	Kilogram/meter	−07 1.00*
Dram (avoirdupois)	Kilogram	−03 1.771 845 195 312 5*
Dram (troy or apothecary)	Kilogram	−03 3.887 934 6*
Dram (U.S. fluid)	Meter^3	−06 3.696 691 195 312 5*
Dyne	Newton	−05 1.00*
Electron volt	Joule	−19 1.602 191 7
Erg	Joule	−07 1.00*
Fahrenheit (temperature)	Kelvin	$t_K = (5/9)(t_F + 459.67)$
Fahrenheit (temperature)	Celsius	$t_c = (5/9)(t_F - 32)$
Faraday (based on carbon 12)	Coulomb	+04 9.68 70
Faraday (chemical)	Coulomb	+04 9.649 57
Faraday (physical)	Coulomb	+04 9.652 19
Fathom	Meter	+00 1.828 8*
Fermi (femtometer)	Meter	+15 1.00*
Fluid ounce (U.S.)	Meter^3	−05 2.957 352 967 25*
Foot	Meter	−01 3.048*
Foot (U.S. survey)	Meter	+00 1200/3937*

Table A.5 *(Continued)*

To Convert from	to	Multiply by
Foot (U.S. survey)	Meter	−01 3.048 006 096
Foot of water (39.2°F)	Newton/meter^2	+03 2.988 98
Footcandle	Lumen/meter^2	+01 1.076 391 0
Footlambert	Candela/meter^2	+00 3.426 259
Free fall, standard	Meter/second^2	+00 9.806 65*
Furlong	Meter	+02 2.011 68*
Gal (galileo)	Meter/second^2	−02 1.00*
Gallon (U.K. liquid)	Meter^3	−03 4.546 087
Gallon (U.S. dry)	Meter^3	−03 4.404 883 770 86*
Gallon (U.S. liquid)	Meter^3	−03 3.785 411 784*
Gamma	Tesla	−09 1.00*
Gauss	Tesla	−04 1.00*
Gilbert	Ampere turn	−01 7.957 747 2
Gill (U.K.)	Meter^3	−04 1.420 652
Gill (U.S.)	Meter^3	−04 1.182 941 2
Grad	Degree (angular)	−01 .900*
Grad	Radian	−02 1.570 796 3
Grain	Kilogram	−05 6.479 891*
Gram	Kilogram	−03 1.00*
Hand	Meter	−01 1.016*
Hectare	Meter^3	+04 1.00*
Hogshead (U.S.)	Meter^3	−01 2.384 809 423 92*
Horsepower (550 ft·lbf/second)	Watt	+02 7.456 998 7
Horsepower (boiler)	Watt	+03 9.809 50
Horsepower (electric)	Watt	+02 7.46*
Horsepower (metric)	Watt	+02 7.354 99
Horsepower (U.K.)	Watt	+02 7.457
Horsepower (water)	Watt	+02 7.460 73
Hour (mean solar)	Second (mean solar)	+03 3.60*
Hour (sidereal)	Second (mean solar)	+03 3.590 170 4
Hundredweight (long)	Kilogram	+01 5.080 234 544*
Hundredweight (short)	Kilogram	+01 4.535 923 7*
Inch	Meter	−02 2.54*
Inch of mercury (32°F)	Newton/meter^2	+03 3.386 389
Inch of mercury (60°F)	Newton/meter^2	+03 3.375 85
Inch of water (39.2°F)	Newton/meter^2	+02 2.490 82
Inch of water (60°F)	Newton/meter^2	+02 2.4884
Kayser	1/meter	+02 1.00*
Kilocalorie (International Steam Table)	Joule	+03 4.186 8
Kilocalorie (mean)	Joule	+03 4.190 02
Kilocalorie (thermochemical)	Joule	+03 4.184*
Kilogram mass	Kilogram	+00 1.00*
Kilogram force (kgf)	Newton	+00 9.806 65*
Kilopound force	Newton	+00 9.806 65*
Kip	Newton	+03 4.448 221 615 260 5*
Knot (international)	Meter/second	−01 5.144 444 444
Lambert	Candela/meter^2	+04 $1/\pi$*
Lambert	Candela/meter^2	+03. 3.183 098 8
Langley	Joule/meter^2	+04 4.184*
Lbf (pound force, avoirdupois)	Newton	+00 4.448 221 615 260 5*
Lbm (pound mass, avoirdupois)	Kilogram	−01 4.535 923 7*
League (U.K. nautical)	Meter	+03 5.559 552*
League (international nautical)	Meter	+03 5.556
League (statute)	Meter	+03 4.828 032*
Light-year	Meter	+15 9.460 55
Link (engineer or ramden)	Meter	−01 3.048*
Link (surveyor or gunter)	Meter	−01 2.011 68*
Liter	Meter^3	−03 1.00*

Table A.5 (Continued)

To Convert from	to	Multiply by
Lux	Lumen/meter^2	+00 1.00*
Maxwell	Weber	−08 1.00*
Meter	Wavelengths Kr 86	+06 1.650 763 73*
Micron	Meter	−06 1.00*
Mil	Meter	−05 2.54*
Mile (U.S. statute)	Meter	+03 1.609 344*
Mile (U.K. nautical)	Meter	+03 1.853 184*
Mile (international nautical)	Meter	+03 1.852*
Mile (U.S. nautical)	Meter	+03 1.852*
Millibar	Newton/meter^2	+02 1.00*
Millimeter of mercury (0°C)	Newton/meter^2	+02 1.333 224
Minute (angle)	Radian	−04 2.908 882 086 66
Minute (mean solar)	Second (mean solar)	+01 6.00*
Minute (sidereal)	Second (mean solar)	+01 5.983 617 4
Month (mean calendar)	Second (mean solar)	+06 2.628*
Nautical mile (international)	Meter	+03 1.852*
Nautical mile (U.S.)	Meter	+03 1.852*
Nautical mile (U.K.)	Meter	+03 1.853 184*
Oersted	Ampere/meter	+01 7.957 747 2
Ounce force (avoirdupois)	Newton	−01 2.780 138 5
Ounce mass (avoirdupois)	Kilogram	−02 2.834 952 312 5*
Ounce mass (troy or apothecary)	Kilogram	−02 3.110 347 68*
Ounce (U.S. fluid)	Meter^3	−05 2.957 352 956 25*
Pace	Meter	−01 7.62*
Parsec (IAU)	Meter	+16 3.085 7
Pascal	Newton/meter^2	+00 1.00*
Peck (U.S.)	Meter^3	−03 8.809 767 541 72*
Pennyweight	Kilogram	−03 1.555 173 84*
Perch	Meter	+00 5.0292*
Phot	Lumen/meter^3	+04 1.00
Pica (printers)	Meter	−03 4.217 517 6*
Pint (U.S. dry)	Meter^3	−04 5.506 104 713 575*
Pint (U.S. liquid)	Meter^3	−04 4.731 764 73*
Point (printers)	Meter	−04 3.514 598*
Poise	Newton second/meter^2	−01 1.00*
Pole	Meter	+00 5.0292*
Pound force (lbf avoirdupois)	Newton	+00 4.448 221 615 260 5*
Pound mass (lbm avoirdupois)	Kilogram	−01 4.535 923 7*
Pound mass (troy or apothecary)	Kilogram	−01 3.732 417 216*
Poundal	Newton	−01 1.382 549 543 76*
Quart (U.S. dry)	Meter^3	−03 1.101 220 942 715*
Quart (U.S. liquid)	Meter^3	−04 9.463 592 5
Rad (radiation dose absorbed)	Joule/kilogram	−02 1.00*
Rankine (temperature)	Kelvin	$t_K = (5/9)t_R$
Rayleigh (rate of photon emission)	1/second meter^2	+10 1.00*
Rhe	Meter^2/newton second	+01 1.00*
Rod	Meter	+00 5.0292*
Roentgen	Coulomb/kilogram	−04 2.579 76*
Rutherford	Disintegration/second	+06 1.00*
Second (angle)	Radian	−06 4.848 136 811
Second (ephemeris)	Second	+00 1.000 000 000
Second (mean solar)	Second (ephemeris)	Consult American Ephemeris and Nautical Almanac
Second (sidereal)	Second (mean solar)	−01 9.972 695 7
Section	Meter^2	+06 2.589 988 110 336*
Scruple (apothecary)	Kilogram	−03 1.295 978 2*

Table A.5 *(Continued)*

To Convert from	to	Multiply by
Shake	Second	−08 1.00
Skein	Meter	+02 1.097 28*
Slug	Kilogram	+01 1.459 390 29
Span	Meter	−01 2.286*
Statampere	Ampere	−10 3.335 640
Statcoulomb	Coulomb	−10 3.335 640
Statfarad	Farad	−12 1.112 650
Stathenry	Henry	+11 8.987 554
Statohm	Ohm	+11 8.987 554
Statute mile (U.S.)	Meter	+03 1.609 344*
Statvolt	Volt	+02 2.997 925
Stere	Meter^3	+00 1.00*
Stilb	Candela/meter^2	+04 1.00
Stoke	Meter^2/second	−04 1.00*
Tablespoon	Meter^3	−05 1.478 676 478 125*
Teaspoon	Meter^3	−06 4.928 921 593 75*
Ton (assay)	Kilogram	−02 2.196 666 6
Ton (long)	Kilogram	+03 1.016 046 908 8*
Ton (metric)	Kilogram	+03 1.00*
Ton (nuclear equivalent of TNT)	Joule	+09 4.20
Ton (register)	Meter^3	+00 2.831 684 659 2*
Ton (short, 2000 pound)	Kilogram	+02 9.071 847 4*
Tonne	Kilogram	+03 1.00*
Torr (0°C)	Newton/meter^2	+02 1.333 22
Township	Meter^2	+07 9.323 957 2
Unit pole	Weber	−07 1.256 637
Yard	Meter	−01 9.144*
Year (calendar)	Second (mean solar)	+07 3.1536*
Year (sidereal)	Second (mean solar)	+07 3.155 815 0
Year (tropical)	Second (mean solar)	+07 3.155 692 6
Year 1900, tropical, Jan., day 0, hour 12	Second (ephemeris)	+07 3.155 692 597 47*
Year 1900, tropical, Jan., day 0, hour 12	Second	+07 3.155 692 597 47*

Table A.6 *Listing Conversion Factors by Physical Quantity*[1]

To Convert from	to	Multiply by
	ACCELERATION	
Foot/second^2	Meter/second^2	−01 3.048*
Free fall, standard	Meter/second^2	+00 9.806 65*
Gal (galileo)	Meter/second^2	−02 1.00*
Inch/second^2	Meter/second^2	−02 2.54*
	AREA	
Acre	Meter^2	+03 4.046 856 422 4*
Are	Meter^2	+02 1.00*
Barn	Meter^2	−28 1.00*
Circular mil	Meter^2	−10 5.067 074 8
Foot^2	Meter^2	−02 9.290 304*
Hectare	Meter^2	+04 1.00*
Inch^2	Meter^2	−04 6.4516*
Mile^2 (U.S. statute)	Meter^2	+06 2.589 988 110 336*
Section	Meter^2	+06 2.589 988 110 336*
Township	Meter^2	+07 9.323 957 2
Yard^2	Meter^2	−01 8.361 273 6*

Table A.6 (Continued)

To Convert from	to	Multiply by
	DENSITY	
Gram/centimeter^3	Kilogram/meter^3	−03 1.00*
Lbm/inch^3	Kilogram/meter^3	+04 2.767 990 5
Lbm/foot^3	Kilogram/meter^3	+01 1.601 846 3
Slug/foot^3	Kilogram/meter^3	+02 5.153 79
	ENERGY	
British thermal unit		
IST before 1956	Joule	+03 1.055 04
IST after 1956	Joule	+03 1.055 056
British thermal unit (mean)	Joule	+03 1.055 87
British thermal unit (thermochemical)	Joule	+03 1.054 350
British thermal unit (39°F)	Joule	+03 1.059 67
British thermal unit (60°F)	Joule	+03 1.054 68
Calorie (International Steam Table)	Joule	+00 4.1868
Calorie (mean)	Joule	+00 4.190 02
Calorie (thermochemical)	Joule	+00 4.184*
Calorie (15°C)	Joule	+00 4.185 80
Calorie (20°C)	Joule	+00 4.181 90
Calorie (kilogram, International Steam Table)	Joule	+03 4.1868
Calorie (kilogram, mean)	Joule	+03 4.190 02
Calorie (kilogram, thermochemical)	Joule	+03 4.184*
Electron volt	Joule	−19 1.602 191 7
Erg	Joule	−07 1.00*
Foot lbf	Joule	+03 1.355 817 9
Foot poundal	Joule	−02 4.214 011 0
Joule (international of 1948)	Joule	+00 1.000 165
Kilocalorie (International Steam Table)	Joule	+03 4.1868
Kilocalorie (mean)	Joule	+03 4.190 02
Kilocalorie (thermochemical)	Joule	+03 4.184*
Kilowatt hour	Joule	+06 3.60*
Kilowatt hour (international of 1948)	Joule	+06 3.600 59
Ton (nuclear equivalent of TNT)	Joule	+09 4.20
Watt hour	Joule	+03 3.60*
	ENERGY/AREA TIME	
Btu (thermochemical)/foot^2 second	Watt/meter^2	+04 1.134 893 1
Btu (thermochemical)/foot^2 minute	Watt/meter^2	+02 1.891 488 5
Btu (thermochemical)/foot^2 hour	Watt/meter^2	+00 3.152 480 8
Btu (thermochemical)/inch^2 second	Watt/meter^2	+06 1.634 246 2
Calorie (thermochemical)/cm^2 minute	Watt/meter^2	+02 6.973 333 3
Erg/centimeter^2 second	Watt/meter^2	−03 1.00*
Watt/centimeter^2	Watt/meter^2	+04 1.00*
	FORCE	
Dyne	Newton	−05 1.00*
Kilogram force (kgf)	Newton	+00 9.806 65*
Kilopound force	Newton	+00 9.806 65*
Kip	Newton	+03 4.448 221 615 260 5*
Lbf (pound force, avoirdupois)	Newton	+00 4.448 221 615 260 5*
Ounce force (avoirdupois)	Newton	+01 2.780 138 5
Pound force, lbf (avoirdupois)	newton	+00 4.448 221 615 260 5*
Poundal	Newton	−01 1.382 549 543 76*
	LENGTH	
Angstrom	Meter	−10 1.00*
Astronomical unit (IAU)	Meter	+11 1.496 00
Astronomical unit (radio)	Meter	+11 1.495 978 9
Cable	Meter	+02 2.194 56*
Caliber	Meter	−04 2.54*
Chain (surveyor or gunter)	Meter	+01 2.011 68*

Table A.6 *(Continued)*

To Convert from	to	Multiply by
	LENGTH *(continued)*	
Chain (engineer or ramden)	Meter	+01 3.048*
Cubit	Meter	−01 4.572*
Fathom	Meter	+00 1.8288*
Fermi (femtometer)	Meter	−15 1.00*
Foot	Meter	−01 3.048*
Foot (U.S. survey)	Meter	+00 1200/3937*
Foot (U.S. survey)	Meter	−01 3.048 006 096
Furlong	Meter	+02 2.011 68*
Hand	Meter	−01 1.016*
Inch	Meter	−02 2.54*
League (U.K. nautical)	Meter	+03 5.559 552*
League (international nautical)	Meter	+03 5.556*
League (statute)	Meter	+03 4.828 032*
Light-year	Meter	+15 9.460 55
Link (engineer or ramden)	Meter	−01 3.048*
Link (surveyor or gunter)	Meter	−01 2.011 68*
Meter	Wavelengths Kr 86	+06 1.650 763 73*
Micron	Meter	−06 1.00*
Mil	Meter	−05 2.54*
Mile (U.S. statute)	Meter	+03 1.609 344*
Mile (U.K. nautical)	Meter	+03 1.853 184*
Mile (international nautical)	Meter	+03 1.852*
Mile (U.S. nautical)	Meter	+03 1.852*
Nautical mile (U.K.)	Meter	+03 1.853 184*
Nautical mile (international)	Meter	+03 1.852*
Nautical mile (U.S.)	Meter	+03 1.852*
Pace	Meter	−01 7.62*
Parsec (IAU)	Meter	+16 3.085 7
Perch	Meter	+00 5.0292*
Pica (printers)	Meter	−03 4.217 517 6*
Point (printers)	Meter	−04 3.514 598*
Pole	Meter	+00 5.0292*
Rod	Meter	+00 5.0292*
Skein	Meter	+02 1.097 28*
Span	Meter	−01 2.286*
Statute mile (U.S.)	Meter	+03 1.609 344*
Yard	Meter	−01 9.144*
	MASS	
Carat (metric)	Kilogram	−04 2.00*
Gram (avoirdupois)	Kilogram	−03 1.771 845 195 312 5*
Gram (troy or apothecary)	Kilogram	−03 3.887 934 6*
Grain	Kilogram	−05 6.479 891*
Gram	Kilogram	−03 1.00*
Hundredweight (long)	Kilogram	+01 5.080 234 544*
Hundredweight (short)	Kilogram	+01 4.535 923 7*
Kgf second^2 meter (mass)	Kilogram	+00 9.806 65*
Kilogram mass	Kilogram	+00 1.00*
Lbm (pound mass, avoirdupois)	Kilogram	−01 4.535 923 7*
Ounce mass (avoirdupois)	Kilogram	−02 2.834 952 312 5*
Ounce mass (troy or apothecary)	Kilogram	−02 3.110 347 68*
Pennyweight	Kilogram	−03 1.555 173 84*
Pound mass, lbm (avoirdupois)	Kilogram	−01 4.535 923 7*
Pound mass (troy or apothecary)	Kilogram	−01 3.732 417 216*
Scruple (apothecary)	Kilogram	−03 1.295 978 2*
Slug	Kilogram	+01 1.459 390 29
Ton (assay)	Kilogram	−02 2.196 666 6
Ton (long)	Kilogram	+03 1.016 046 908 8*
Ton (metric)	Kilogram	+03 1.00*
Ton (short, 2000 pound)	Kilogram	+02 9.071 847 4*
Tonne	Kilogram	+03 1.00*

Table A.6 *(Continued)*

To Convert from	to	Multiply by
	POWER	
Btu (thermochemical)/second	Watt	+03 1.054 350 264 488
Btu (thermochemical)/minute	Watt	+01 1.757 250 4
Calorie (thermochemical)/second	Watt	+00 4.184*
Calorie (thermochemical)/minute	Watt	−02 6.973 333 3
Foot lbf/hour	Watt	−04 3.766 161 0
Foot lbf/minute	Watt	−02 2.259 696 6
Foot lbf/second	Watt	+00 1.355 817 9
Horsepower (550 ft·lbf/second)	Watt	+02 7.456 998 7
Horsepower (boiler)	Watt	+03 9.809 50
Horsepower (electric)	Watt	+02 7.46*
Horsepower (metric)	Watt	+02 7.354 99
Horsepower (U.K.)	Watt	+02 7.457
Horsepower (water)	Watt	+02 7.460 43
Kilocalorie (thermochemical)/minute	Watt	+01 6.973 333 3
Kilocalorie (thermochemical)/second	Watt	+03 4.184*
Watt (international of 1948)	Watt	+00 1.000 165
	PRESSURE	
Atmosphere	Newton/meter^2	+05 1.013 25*
Bar	Newton/meter^2	+05 1.00*
Barye	Newton/meter^2	−01 1.00*
Centimeter of mercury (0°C)	Newton/meter^2	+03 1.333 22
Centimeter of water (4°C)	Newton/meter^2	+01 9.806 38
Dyne/centimeter^2	Newton/meter^2	−01 1.00*
Foot of water (39.2°F)	Newton/meter^2	+03 2.988 988
Inch of mercury (32°F)	Newton/meter^2	+03 3.386 389
Inch of mercury (60°F)	Newton/meter^2	+03 3.376 85
Inch of water (39.2°F)	Newton/meter^2	+02 2.480 82
Inch of water (60°F)	Newton/meter^2	+02 2.4884
Kgf/centimeter^2	Newton/meter^2	+04 9.806 65*
Kgf/meter^2	Newton/meter^2	+00 9.806 65*
Lbf/foot^2	Newton/meter^2	+01 4.788 025 8
Lbf/inch^2 (psi)	Newton/meter^2	+03 6.894 757 2
Millibar	Newton/meter^2	+02 1.00*
Millimeter of mercury (0°C)	Newton/meter^2	+02 1.333 224
Pascal	Newton/meter^2	+00 1.00*
Psi (lbf/inch^2)	Newton/meter^2	+03 6.894 757 2
Torr (0°C)	Newton/meter^2	+02 1.333 22
	SPEED	
Foot/hour	Meter/second	−05 8.466 666 6
Foot/minute	Meter/second	−03 5.08*
Foot/second	Meter/second	−01 3.048*
Inch/second	Meter/second	−02 2.54*
Kilometer/hour	Meter/second	−01 2.777 777 8
Knot (international)	Meter/second	−01 5.144 444 444
Mile/hour (U.S. statute)	Meter/second	−01 4.4704*
Mile/minute (U.S. statute)	Meter/second	+01 2.682 24*
Mile/second (U.S. statute)	Meter/second	+03 1.609 344*
	TEMPERATURE	
Celsius	Kelvin	$t_K = t_C + 273.15$
Fahrenheit	Kelvin	$t_K = (5/9)(t_F + 459.67)$
Fahrenheit	Celsius	$t_C = (5/9)(t_F - 32)$
Rankine	Kelvin	$t_K = (5/9)t_R$

Table A.6 *(Continued)*

To Convert from	to	Multiply by
	TIME	
Day (mean solar)	Second (mean solar)	+04 8.64*
Day (sidereal)	Second (mean solar)	+04 8.616 409 0
Hour (mean solar)	Second (mean solar)	+03 3.60*
Hour (sidereal)	Second (mean solar)	+03 3.590 170 4
Minute (mean solar)	Second (mean solar)	+01 6.00*
Minute (sidereal)	Second (mean solar)	+01 5.983 617 4
Month (mean calendar)	Second (mean solar)	+06 2.628*
Second (ephemeris)	Second	+00 1.000 000 000
Second (mean solar)	Second (ephemeris)	Consult American Ephemeris and Nautical Almanac
Second (sidereal)	Second (mean solar)	−01 9.972 695 7
Year (calendar)	Second (mean solar)	+07 3.1536*
Year (sidereal)	Second (mean solar)	+07 3.155 815 0
Year (tropical)	Second (mean solar)	+07 3.155 692 6
Year 1900, tropical, Jan., day 0, hour 12	Second (ephemeris)	+07 3.155 692 597 47*
Year 1900, tropical, Jan., day 0, hour 12	Second	+07 3.155 692 597 47
	VISCOSITY	
Centistoke	$Meter^2$/second	−06 1.00*
Stoke	$Meter^2$/second	−04 1.00*
$Foot^2$/second	$Meter^2$/second	−02 9.290 304*
Centipoise	Newton second/$meter^2$	−03 1.00*
Lbm/foot second	Newton second/$meter^2$	+00 1.488 163 9
Lbf·second/$foot^2$	Newton second/$meter^2$	+01 4.788 025 8
Poise	Newton second/$meter^2$	−01 1.00*
Poundal second/$foot^2$	Newton second/$meter^2$	+00 1.488 163 9
Slug/foot second	Newton second/$meter^2$	+01 4.788 025 8
Rhe	$Meter^2$/newton second	+01 1.00*
	VOLUME	
Acre foot	$Meter^3$	+03 1.233 481 837 547 52*
Barrel (petroleum, 42 gallons)	$Meter^3$	−01 1.589 873
Board foot	$Meter^3$	−03 2.359 737 216*
Bushel (U.S.)	$Meter^3$	−02 3.523 907 016 688*
Cord	$Meter^3$	+00 3.624 556 3
Cup	$Meter^3$	−04 2.365 882 365*
Dram (U.S. fluid)	$Meter^3$	−06 3.696 691 195 312 5*
Fluid ounce (U.S.)	$Meter^3$	−05 2.957 352 946 25*
$Foot^3$	$Meter^3$	−02 2.831 684 659 2*
Gallon (U.K. liquid)	$Meter^3$	−03 4.546 087
Gallon (U.S. dry)	$Meter^3$	−03 4.404 883 770 86*
Gallon (U.S. liquid)	$Meter^3$	−03 3.785 411 784*
Gill (U.K.)	$Meter^3$	−04 1.420 652
Gill (U.S.)	$Meter^3$	−04 1.182 941 2
Hogshead (U.S.)	$Meter^3$	−01 2.384 809 423 92*
$Inch^3$	$Meter^3$	−05 1.638 706 4*
Liter	$Meter^3$	−03 1.00*
Ounce (U.S. fluid)	$Meter^3$	−05 2.957 352 956 25*
Peck (U.S.)	$Meter^3$	−03 8.809 767 541 72*
Pint (U.S. dry)	$Meter^3$	−04 5.506 104 713 575*
Pint (U.S. liquid)	$Meter^3$	−04 4.731 764 73*
Quart (U.S. dry)	$Meter^3$	−03 1.101 220 942 715*
Quart (U.S. liquid)	$Meter^3$	−04 9.463 592 5
Stere	$Meter^3$	+00 1.00*
Tablespoon	$Meter^3$	−05 1.478 676 478 125*
Teaspoon	$Meter^3$	−06 4.928 921 593 75*
Ton (register)	$Meter^3$	+00 2.831 684 659 2*
$Yard^3$	$Meter^3$	−01 7.645 548 579 84*

Conversion Factor Tables[3]

Table A.7 ***Length (L)***

Multiply Number of → by → to Obtain ↓	Centimeters	Feet	Inches	Kilometers	Nautical Miles	Meters	Mils	Miles	Millimeters	Yards
Centimeters	1	30.48	2.540	10^5	1.853×10^5	100	2.540×10^{-3}	1.609×10^5	0.1	91.44
Feet	3.281×10^{-2}	1	8.333×10^{-2}	3281	6080.27	3.281	8.333×10^{-5}	5280	3.281×10^{-3}	3
Inches	0.3937	12	1	3.937×10^4	7.296×10^4	39.37	0.001	6.336×10^4	3.937×10^{-2}	36
Kilometers	10^{-5}	3.048×10^{-4}	2.540×10^{-5}	1	1.853	0.001	2.540×10^{-8}	1.609	10^{-6}	9.144×10^{-4}
Nautical miles		1.645×10^{-4}		0.5396	1	5.396×10^{-4}		0.8684		4.934×10^{-4}
Meters	0.01	0.3048	2.540×10^{-2}	1000	1853	1		1609	0.001	0.9144
Mils	393.7	1.2×10^4	1000	3.937×10^7		3.937×10^4	1		39.37	3.6×10^4
Miles	6.214×10^{-6}	1.894×10^{-4}	1.578×10^{-5}	0.6214	1.1516	6.214×10^{-4}		1	6.214×10^{-7}	5.682×10^{-4}
Millimeters	10	304.8	25.40	10^6		1000	2.540×10^{-2}		1	914.4
Yards	1.094×10^{-2}	0.3333	2.778×10^{-2}	1094	2027	1.094	2.778×10^{-5}	1760	1.094×10^{-3}	1

Table A.8 *Area (L^2)*

Multiply Number of → by → to Obtain ↓	Acres	Circular Mils	Square Centimeters	Square Feet	Square Inches	Square Kilometers	Square Meters	Square Miles	Square Millimeters	Square Yards
Acres	1			2.296×10^{-5}		247.1	2.471×10^{-4}	640		2.066×10^{-4}
Circular mils		1	1.973×10^{5}	1.833×10^{8}	1.273×10^{6}		1.973×10^{9}		1973	
Square centimeters		5.067×10^{-6}	1	929.0	6.452	10^{10}	10^{4}	2.590×10^{10}	0.01	8361
Square feet	4.356×10^{4}		1.076×10^{-3}	1	6.944×10^{-3}	1.076×10^{7}	10.76	2.788×10^{7}	1.076×10^{-5}	9
Square inches	6,272,640	7.854×10^{-7}	0.1550	144	1	1.550×10^{9}	1550	4.015×10^{9}	1.550×10^{-3}	1296
Square kilometers	4.047×10^{-3}		10^{-10}	9.290×10^{-8}	6.452×10^{-10}	1	10^{-6}	2.590	10^{-12}	8.361×10^{-7}
Square meters	4047		0.0001	9.290×10^{-2}	6.452×10^{-4}	10^{6}	1	2.590×10^{6}	10^{-6}	0.8361
Square miles	1.562×10^{-3}		3.861×10^{-11}	3.587×10^{-8}		0.3861	3.861×10^{-7}	1	3.861×10^{-13}	3.228×10^{-7}
Square millimeters		5.067×10^{-4}	100	9.290×10^{4}	645.2	10^{12}	10^{6}		1	8.361×10^{5}
Square yards	4840		1.196×10^{-4}	0.1111	7.716×10^{-4}	1.196×10^{6}	1.196	3.098×10^{6}	1.196×10^{-6}	1

Table A.9 *Volume (L^3)*

Multiply Number of → by → to Obtain ↓	Bushels (dry)	Cubic Centimeters	Cubic Feet	Cubic Inches	Cubic Meters	Cubic Yards	Gallons (liquid)	Liters	Pints (liquid)	Quarts (liquid)
Bushels (dry)	1		0.8036	4.651×10^{-4}	28.38			2.838×10^{-2}		
Cubic centimeters	3.524×10^{4}	1	2.832×10^{4}	16.39	10^{6}	7.646×10^{5}	3785	1000	473.2	946.4
Cubic feet	1.2445	3.531×10^{-5}	1	5.787×10^{-4}	35.31	27	0.1337	3.531×10^{-2}	1.671×10^{-2}	3.342×10^{-2}
Cubic inches	2150.4	6.102×10^{-2}	1728	1	6.102×10^{4}	46,656	231	61.02	28.87	57.75
Cubic meters	3.524×10^{-2}	10^{-6}	2.832×10^{-2}	1.639×10^{-5}	1	0.7646	3.785×10^{-3}	0.001	4.732×10^{-4}	9.464×10^{-4}
Cubic yards		1.308×10^{-6}	3.704×10^{-2}	2.143×10^{-5}	1.308	1	4.951×10^{-3}	1.308×10^{-3}	6.189×10^{-4}	1.238×10^{-3}
Gallons (liquid)		2.642×10^{-4}	7.481	4.329×10^{-3}	264.2	202.0	1	0.2642	0.125	0.25
Liters	35.24	0.001	28.32	1.639×10^{-2}	1000	764.6	3.785	1	0.4732	0.9464
Pints (liquid)		2.113×10^{-3}	59.84	3.463×10^{-2}	2113	1616	8	2.113	1	2
Quarts (liquid)		1.057×10^{-3}	29.92	1.732×10^{-2}	1057	807.9	4	1.057	0.5	1

Table A.10 *Plane Angle (no dimensions)*

Multiply Number of → by → to Obtain ↓	Degrees	Minutes	Quadrants	Radians	Revolutions[a] (circumferences)	Seconds
Degrees	1	1.667×10^{-2}	90	57.30	360	2.778×10^{-4}
Minutes	60	1	5400	3438	2.16×10^{4}	1.667×10^{-2}
Quadrants	1.111×10^{-2}	1.852×10^{-4}	1	0.6366	4	3.087×10^{-6}
Radians[a]	1.745×10^{-2}	2.909×10^{-4}	1.571	1	6.283	4.848×10^{-6}
Revolutions[a] (circumferences)	2.788×10^{-3}	4.630×10^{-5}	0.25	0.1591	1	7.716×10^{-7}
Seconds	3600	60	3.24×10^{5}	2.063×10^{5}	1.296×10^{6}	1

[a]2π rad = 1 circumference = 360 degrees by definition.

Table A.11 *Linear Velocity (LT^{-1})*

Multiply Number of → by → to Obtain ↓	Centimeters per Second	Feet per Minute	Feet per Second	Kilometers per Hour	Kilometers per Minute	Knots[a]	Meters per Minute	Meters per Second	Miles per Hour	Miles per Minute
Centimeters per second	1	0.5080	30.48	27.78	1667	51.48	1.667	100	44.70	2682
Feet per minute	1.969	1	60	54.68	3281	101.3	3.281	196.8	88	5280
Feet per second	3.281×10^{-2}	1.667×10^{-2}	1	0.9113	54.68	1.689	5.468×10^{-2}	3.281	1.467	88
Kilometers per hour	0.036	1.829×10^{-2}	1.097	1	60	1.853	0.06	3.6	1.609	96.54
Kilometers per minute	0.0006	3.048×10^{-4}	1.829×10^{-2}	1.667×10^{-2}	1	3.088×10^{-2}	0.001	0.06	2.682×10^{-2}	1.609
Knots[a]	1.943×10^{-2}	9.868×10^{-3}	0.5921	0.5396	32.38	1	3.238×10^{-2}	1.943	0.8684	52.10
Meters per minute	0.6	0.3048	18.29	16.67	1000	30.88	1	60	26.82	1609
Meters per second	0.01	5.080×10^{-3}	0.3048	0.2778	16.67	0.5148	1.667×10^{-2}	1	0.4470	26.82
Miles per hour	2.237×10^{-2}	1.136×10^{-2}	0.6818	0.6214	37.28	1.152	3.728×10^{-2}	2.237	1	60
Miles per minute	3.728×10^{-4}	1.892×10^{-4}	1.136×10^{-2}	1.036×10^{-2}	0.6214	1.919×10^{-2}	6.214×10^{-4}	3.728×10^{-2}	1.667×10^{-2}	1

[a]Nautical miles per hour.

Table A.12 ***Linear Acceleration (LT^{-2})***

Multiply Number of → by → to Obtain ↓	Centimeters per Second per Second	Feet per Second per Second	Kilometers per Hour per Second	Meters per Second per Second	Miles per Hour per Second
Centimeters per Second per Second	1	30.48	27.78	100	44.70
Feet per Second per Second	3.281×10^{-2}	1	0.9113	3.281	1.467
Kilometers per Hour per Second	0.036	1.097	1	3.6	1.609
Meters per Second per Second	0.01	0.3048	0.2778	1	0.4470
Miles per Hour per Second	2.237×10^{-2}	0.6818	0.6214	2.237	1

The (standard) acceleration due to gravity (g_0) = 908.7 cm/s^2 = 32.17 ft/s^2 = 35.30 km/h·s = 9.807 m/s^2 = 21.94 mph/s.

Table A.13 ***Mass (M) and Weight****

Multiply Number of → by → to Obtain ↓	Grains	Grams	Kilograms	Milligrams	Ounces†	Pounds†	Tons (long)	Tons (metric)	Tons (short)
Grains	1	15.43	1.543×10^{4}	1.543×10^{-2}	437.5	7000			
Grams	6.481×10^{-2}	1	1000	0.001	28.35	453.6	1.016×10^{6}	$\times 10^{6}$	9.072×10^{5}
Kilograms	6.481×10^{-5}	0.001	1	10^{-6}	2.835×10^{-2}	0.4536	1016	1000	907.2
Milligrams	64.81	1000	10^{6}	1	2.835×10^{4}	4.536×10^{5}	1.016×10^{9}	10^{9}	9.072×10^{8}
Ounces	2.286×10^{-3}	3.527×10^{-2}	35.27	3.527×10^{-5}	1	16	3.584×10^{4}	3.527×10^{4}	3.2×10^{4}
Pounds	1.429×10^{-4}	2.205×10^{-3}	2.205	2.205×10^{-6}	6.250×10^{-2}	1	2240	2205	2000
Tons (long)		9.842×10^{-7}	9.842×10^{-4}	9.842×10^{-10}	2.790×10^{-5}	4.464×10^{-4}	1	0.9842	0.8929
Tons (metric)		10^{-6}	0.001	10^{-9}	2.835×10^{-5}	4.536×10^{-4}	1.016	1	0.9072
Tons (short)		1.102×10^{-6}	1.102×10^{-3}	1.102×10^{-9}	3.125×10^{-5}	0.0005	1.120	1.102	1

*These conversion factors apply to the gravitational units of force having the corresponding names.
†Avoirdupois pounds and ounces.

Table A.14 ***Density or Mass per Unit Volume (ML^{-3})***

Multiply Number of → by → to Obtain ↓	Grams per Cubic Centimeter	Kilograms per Cubic Meter	Pounds per Cubic Foot	Pounds per Cubic Inch
Grams per cubic centimeter	1	0.001	1.602×10^{-2}	27.68
Kilograms per cubic meter	1000	1	16.02	2.768×10^{4}
Pounds per cubic foot	62.43	6.243×10^{-2}	1	1728
Pounds per cubic inch	3.613×10^{-2}	3.613×10^{-5}	5.787×10^{-4}	1
Pounds per mil foot[a]	3.405×10^{-7}	3.405×10^{-10}	5.456×10^{-9}	9.425×10^{-6}

[a]Unit of volume is a volume one foot long and one circular mil in cross-section area.

Table A.15 ***Force (MLT^{-2}) or (F)***

Multiply Number of → by → to Obtain ↓	Dynes	Grams	Joules per Centimeter	Newtons or Joules per Meter	Kilograms	Pounds	Poundals
Dynes	1	980.7	10^{7}	10^{5}	9.807×10^{5}	4.448×10^{5}	1.383×10^{4}
Grams	1.020×10^{-3}	1	1.020×10^{4}	102.0	1000	453.6	14.10
Joules per centimeter	10^{-7}	9.807×10^{-5}	1	0.01	9.807×10^{-2}	4.448×10^{-2}	1.383×10^{-3}
Newtons or joules per meter	10^{-5}	9.807×10^{-3}	100	1	9.807	4.448	0.1383
Kilograms	1.020×10^{-6}	0.001	10.20	0.1020	1	0.4536	1.410×10^{-2}
Pounds	2.248×10^{-6}	2.205×10^{-3}	22.48	0.2248	2.205	1	3.108×10^{-2}
Poundals	7.233×10^{-5}	7.093×10^{-2}	723.3	7.233	70.93	32.17	1

Conversion factors between absolute and gravitational units apply only under standard acceleration due to gravity conditions.

Table A.16 ***Pressure or Force per Unit Area ($ML^{-1}T^{-2}$) or (FL^{-2})***

Multiply Number of → by → to Obtain ↓	Atmospheres[a]	Baryes or Dynes per Square Centimeter	Centimeters of Mercury at 0°C[b]	Inches of Mercury at 0°C[b]	Inches of Water at 4°C	Kilograms per Square Meter[c]	Pounds per Square Foot	Pounds per Square Inch	Tons (short) per Square Foot	Pascal
Atmospheres[a]	1	9.869×10^{-7}	1.316×10^{-2}	3.342×10^{-2}	2.458×10^{-3}	9.678×10^{-5}	4.725×10^{-4}	6.804×10^{-2}	0.9450	9.689×10^{-6}
Baryes or dynes per square centimeter	1.013×10^{6}	1	1.333×10^{4}	3.386×10^{4}	2.491×10^{-3}	98.07	478.8	6.895×10^{4}	9.576×10^{5}	10
Centimeters of mercury at 0°C[b]	76.00	7.501×10^{-5}	1	2.540	0.1868	7.356×10^{-3}	3.591×10^{-2}	5.171	71.83	7.501×10^{-4}
Inches of mercury at 0°C[b]	29.92	2.953×10^{-5}	0.3937	1	7.355×10^{-2}	2.896×10^{-3}	1.414×10^{-2}	2.036	28.28	2.953×10^{-4}
Inches of water at 4°C	406.8	4.015×10^{-4}	5.354	13.60	1	3.937×10^{-2}	0.1922	27.68	384.5	4.015×10^{-3}
Kilograms per square meter[c]	1.033×10^{4}	1.020×10^{-2}	136.0	345.3	25.40	1	4.882	703.1	9765	0.1020
Pounds per square foot	2117	2.089×10^{-3}	27.85	70.73	5.204	0.2048	1	144	2000	2.089×10^{-2}
Pounds per square inch	14.70	1.450×10^{-5}	0.1934	0.4912	3.613×10^{-2}	1.422×10^{-3}	6.944×10^{-3}	1	13.89	1.450×10^{-4}
Tons (short) per square foot	1.058	1.044×10^{-6}	1.392×10^{-2}	3.536×10^{-2}	2.601×10^{-3}	1.024×10^{-4}	0.0005	0.072	1	1.044×10^{-5}
Pascal	1.013×10^{5}	10^{-1}	1.333×10^{3}	3.386×10^{3}	2.49×10^{2}	9.807	47.88	6.895×10^{3}	9.576×10^{4}	1

[a]Definition: One atmosphere (standard) = 76 cm of mercury at 0°C.

[b]To convert height h of a column of mercury at t degrees centigrade to the equivalent height h_0 at 0°C, use $h_0 = h[1 - (m - l)t/(1 + mt)]$ where $m = 0.0001818$ and $l = 18.4 \times 10^{-6}$ if the scale is engraved on brass; $l = 8.5 \times 10^{-6}$ if on glass. This assumes the scale is correct at 0°C; for other cases (any liquid) see *International Critical Tables,* Vol. 1 (1968).

[c]$1\ g/cm^2 = 10\ kg/m^2$.

Table A.17 *Energy, Work, and Heat (ML^2T^{-2}) or (FL)*

Multiply Number of → by → to Obtain ↓	British Thermal Units[a]	Centimeter Grams	Ergs or Centimeter Dynes	Foot Pounds	Horsepower Hours	Joules[b] or Watt Seconds	Kilogram Calories[a]	Kilowatt Hours	Meter Kilograms	Watt Hours
British thermal units[a]	1	9.297×10^{-8}	9.480×10^{-11}	1.285×10^{-3}	2545	9.480×10^{-4}	3.969	3413	9.297×10^{-3}	3.413
Centimeter grams	1.076×10^{7}	1	1.020×10^{-3}	1.383×10^{4}	2.737×10^{10}	1.020×10^{4}	4.269×10^{7}	3.671×10^{10}	10^{5}	3.671×10^{7}
Ergs or centimeter dynes	1.055×10^{10}	980.7	1	1.356×10^{7}	2.684×10^{12}	10^{7}	4.186×10^{10}	3.6×10^{13}	9.807×10^{7}	3.6×10^{10}
Foot pounds	778.0	7.233×10^{-5}	7.367×10^{-8}	1	1.98×10^{6}	0.7376	3087	2.655×10^{6}	7.233	2655
Horsepower hours	3.929×10^{-4}	3.654×10^{-11}	3.722×10^{-14}	5.050×10^{-7}	1	3.722×10^{-7}	1.559×10^{-3}	1.341	3.653×10^{-6}	1.341×10^{-3}
Joules[b] or watt seconds	1054.8	9.807×10^{-5}	10^{-7}	1.356	2.684×10^{6}	1	4186	3.6×10^{6}	9.807	3600
Kilogram calories[a]	0.2520	2.343×10^{-8}	2.389×10^{-11}	3.239×10^{-4}	641.3	2.389×10^{-4}	1	860.0	2.343×10^{-3}	0.8600
Kilowatt hours	2.930×10^{-4}	2.724×10^{-11}	2.778×10^{-14}	3.766×10^{-7}	0.7457	2.788×10^{-7}	1.163×10^{-3}	1	2.724×10^{-6}	0.001
Meter kilograms	107.6	10^{-5}	1.020×10^{-8}	0.1383	2.737×10^{5}	0.1020	426.9	3.671×10^{5}	1	367.1
Watt hours	0.2930	2.724×10^{-8}	2.778×10^{-11}	3.766×10^{-4}	745.7	2.778×10^{-4}	1.163	1000	2.724×10^{-3}	1

The *horsepower* used in Tables A.17 and A.18 is equal to 550 foot pounds per second by definition. Other definitions are one horsepower equals 746 watts (U.S. and Great Britain) and one horsepower equals 736 watts (continental Europe). Neither of these latter definitions is equivalent to the first; the *horsepowers* defined in these latter definitions are widely used in the rating of electrical machinery.

[a]Mean calorie and Btu used throughout. One gram-calorie = 0.001 kilogram-calorie; one Ostwald calorie = 0.1 kilogram-calorie.The IT cal, 1000 international steam table calories, has been defined as the 1/860th part of the international kilowatt-hour (see *Mechanical Engineering,* Nov., 1935, p. 710). Its value is very nearly equal to the mean kilogram-calorie, 1 IT cal-1.00037 kilogram-calories (mean). 1 Btu = 251.996 IT cal.

[b]Absolute joule, defined as 10^7 ergs. The international joule, based on the international ohm and ampere, equals 1.0003 absolute joules.

Table A.18 ***Power or Rate of Doing Work (ML^2T^{-3}) or (FLT^{-1})***

Multiply Number of → by → to Obtain ↓	British Thermal Units per Minute	Ergs per Second	Foot Pounds per Minute	Foot Pounds per Second	Horsepower	Kilogram Calories per Minute	Kilowatts	Metric Horsepower	Watts
British thermal units per minute	1	5.689×10^{-9}	1.285×10^{-3}	7.712×10^{-2}	42.41	3.969	56.89	41.83	5.689×10^{-2}
Ergs per second	1.758×10^{8}	1	2.259×10^{5}	1.356×10^{7}	7.457×10^{9}	6.977×10^{8}	10^{10}	7.355×10^{9}	10^{7}
Foot pounds per minute	778.0	4.426×10^{-6}	1	60	3.3×10^{4}	3087	4.426×10^{4}	3.255×10^{4}	44.26
Foot pounds per second	12.97	7.376×10^{-8}	1.667×10^{-2}	1	550	51.44	737.6	542.5	0.7376
Horsepower	2.357×10^{-2}	1.341×10^{-10}	3.030×10^{-5}	1.818×10^{-3}	1	9.355×10^{-2}	1.341	0.9863	1.341×10^{-3}
Kilogram calories per minute	0.2520	1.433×10^{-9}	3.239×10^{-4}	1.943×10^{-2}	10.69	1	14.33	10.54	1.433×10^{-2}
Kilowatts	0.01758	10^{-10}	2.260×10^{-5}	1.356×10^{-3}	0.7457	0.06977×10^{-2}	1	0.7355	0.001
Metric horsepower	2.390×10^{-2}	1.360×10^{-10}	3.072×10^{-5}	1.843×10^{-3}	1.014	9.485×10^{-2}	1.360	1	1.360×10^{-3}
Watts	17.58	10^{-7}	2.260×10^{-2}	1.356	745.7	69.77	1000	735.5	1

1 Cheval vapeur = 75 kilogram meters per second

1 Poncelet = 100 kilogram meters per second

See general note to Table A.17.

Table A.19 ***Heat Flux (power/area)***

From → Multiply by → to Obtain ↓	Btu/(min·ft²)	Btu/(s·ft²)	kW/m²	W/m²	W/cm²
Btu/(min·ft²)	1	1.6×10^{-2}	5.28	5.2×10^{-3}	5.2×10^{-1}
Btu/(s·ft²)	60	1	6.81×10^{-2}	8.8×10^{-5}	8.8×10^{-3}
kW/m²	0.18923	11.3565	1	10^{-3}	10^{-1}
W/m²	189.273	1.1356×10^{4}	10^{3}	1	10^{4}
W/cm²	1.89273	1.1356×10^{2}	10	10^{-4}	1
kg-cal/s·m²	6.135×10^{-6}	1.02×10^{-7}	8.60400×10^{5}	8.6×10^{2}	8.604×10^{4}
kg-cal/s·m²	3.681×10^{-4}	6.07×10^{-6}	1.434×10^{4}	1.4341×10^{1}	1.434×10^{3}

Table A.20 *Specific Heat ($L^2T^{-2}t^{-1}$, t = temperature)*

To change specific heat in gram calories per gram per degree centigrade to the units given in any line of the following table, multiply by the factor in the last column.

Unit of Heat or Energy	Unit of Mass	Temperature Scale[a]	Factor
Gram calories	Gram	Centigrade	1
Kilogram calories	Kilogram	Centigrade	1
British thermal units	Pound	Centigrade	1.800
British thermal units	Pound	Fahrenheit	1.000
Joules	Gram	Centigrade	4.186
Joules	Pound	Fahrenheit	1055
Joules	Kilogram	Kelvin	4.187×10^{3}
Kilowatt hours	Kilogram	Centigrade	1.163×10^{-3}
Kilowatt hours	Pound	Fahrenheit	2.930×10^{-4}

[a]Temperature conversion formulae:

t_C = temperature in centigrade degrees

t_f = temperature in Fahrenheit degrees

t_K = temperature in kelvin degrees

$$1°\text{F} = \frac{5}{9}°\text{C}$$

$$1\ \text{K} = 1°\text{C}$$

$$t_C = \frac{5}{9}(t_f - 32)$$

$$t_f = \frac{9}{5}t_C + 32$$

$$t_K = t_C + 273$$

Table A.21 *Thermal Conductivity ($LMT^{-3}t^{-1}$)*

From → / Multiply by → / to Obtain ↓	Btu·ft per h·ft²·°F	Btu·in. per h·ft²·°F	Btu·in. per s·ft²·°F	Joules per m·s·°C	Kcal per m·h·°C	Erg per cm·s·°C	Kcal per m·s·°C	Cal per cm·s·°C	W per ft·°C	W per m·K
Btu·ft per h·ft²·°F	1	8.333×10^{-2}	3.0×10^{2}	5.778×10^{-1}	6.720×10^{-1}	5.778×10^{-6}	2.419×10^{3}	2.419×10^{2}	1.895	5.778×10^{-1}
Btu·in. per h·ft²·°F	12	1	3.6×10^{3}	6.933	8.064	6.933×10^{-5}	2.903×10^{4}	2.903×10^{3}	2.275×10^{1}	6.933
Btu·in. per s·ft²·°F	3.333×10^{-3}	2.778×10^{-4}	1	1.926×10^{-3}	2.240×10^{-3}	1.926×10^{-8}	8.064	8.064×10^{-1}	6.319×10^{-3}	1.926×10^{-3}
Joules per m·s·°C	1.731	1.442×10^{-1}	5.192×10^{2}	1	1.163	1.000×10^{-5}	4.187×10^{3}	4.187×10^{2}	3.281	1.0
Kcal per m·h·°C	1.483	1.240×10^{-1}	4.465×10^{2}	8.599×10^{-1}	1	8.599×10^{-6}	3.6×10^{3}	3.6×10^{2}	2.821	8.599×10^{-1}
Erg per cm·s·°C	1.731×10^{5}	1.442×10^{4}	5.192×10^{7}	1.0×10^{5}	1.163×10^{5}	1	4.187×10^{8}	4.187×10^{7}	3.281×10^{5}	1.0×10^{5}
Kcal per m·s·°C	4.134×10^{-4}	3.445×10^{-5}	1.240×10^{-1}	2.388×10^{-4}	2.778×10^{-4}	2.388×10^{-9}	1	1.0×10^{-1}	7.835×10^{-4}	2.388×10^{-4}
Cal per cm·s·°C	4.134×10^{-3}	3.445×10^{-4}	1.240	2.388×10^{-3}	2.778×10^{-3}	2.388×10^{-8}	10	1	7.835×10^{-3}	2.388×10^{-3}
W per ft·°C	5.276×10^{-1}	4.395×10^{-2}	1.582×10^{2}	3.048×10^{-1}	3.545×10^{-1}	3.048×10^{-6}	1.276×10^{3}	1.276×10^{2}	1	3.048×10^{-1}
W per m·K	1.731	1.442×10^{-1}	5.192×10^{2}	1.0	1.163	1.00×10^{-5}	4.187×10^{3}	4.187×10^{2}	3.281	1

International Table Btu = 1.055056×10^{3} joules; and International Table cal = 4.1868 joules are used throughout.

APPENDIX B

Thermophysical Property Data

Table B.1 ***Approximate Properties of Common Gases***[3]

English (FSS) Units

	Engineering Gas Constant, R (ft-lb/slug·R)	Universal Gas Constant, $\mathcal{R} = mR$ (ft-lb/slug·R)	Adiabatic Exponent, k	Specific Heat at Constant Pressure, c_p (ft-lb/slug·R)	Viscosity at 68°F (20°C), $\mu \times 10^5$ (lb-s/ft^2)
Carbon dioxide	1,123	49,419	1.28	5,132	0.0307
Oxygen	1,554	49,741	1.40	5,437	0.0419
Air	1,715	49,709	1.40	6,000	0.0377
Nitrogen	1,773	49,644	1.40	6,210	0.0368
Methane	3,098	49,644	1.31	13,095	0.028
Helium	12,419	49,677	1.66	31,235	0.0411
Hydrogen	24,677	49,741	1.40	86,387	0.0189

SI Units

	R (J/kg·K)	$\mathcal{R} = mR$ (J/kg·K)	k	c_p (J/kg·K)	$\mu \times 10^5$ (Pa·s)
Carbon dioxide	187.8	8,264	1.28	858.2	1.47
Oxygen	259.9	8,318	1.40	909.2	2.01
Air	286.8	8,313	1.40	1,003	1.81
Nitrogen	296.5	8,302	1.40	1,038	1.76
Methane	518.1	8,302	1.31	2,190	1.34
Helium	2,076.8	8,307	1.66	5,223	1.97
Hydrogen	4,126.6	8,318	1.40	14,446	0.90

Table B.2 ***Thermophysical Property Values for Gases at Standard Atmospheric Pressure***[4]

T (K)	ρ (kg/m^3)	c_p (Ws/kg·K)	μ (kg/ms)	ν (m^2/s)	k (W/m·K)	α (m^2/s)	Pr
				Air			
100	3.6010	1.0266×10^3	0.6924×10^{-5}	1.923×10^{-6}	0.009246	0.0250×10^{-4}	0.768
150	2.3675	1.0099	1.0283	4.343	0.013735	0.0574	0.756
200	1.7684	1.0061	1.3289	7.514	0.01809	0.1016	0.739
250	1.4128	1.0053	1.488	10.53	0.02227	0.1568	0.722
300	1.1774	1.0057	1.983	16.84	0.02624	0.2216	0.708
350	0.9980	1.0090	2.075	20.76	0.03003	0.2983	0.697
400	0.8826	1.0140	2.286	25.90	0.03365	0.3760	0.689
450	0.7833	1.0207	2.484	31.71	0.03707	0.4636	0.683
500	0.7048	1.0295	2.671	37.90	0.04038	0.5564	0.680
550	0.6423	1.0392	2.848	44.27	0.04360	0.6532	0.680
600	0.5879	1.0551	3.018	51.34	0.04659	0.7512	0.682
650	0.5430	1.0635	3.177	58.51	0.04953	0.8578	0.682
700	0.5030	1.0752	3.332	66.25	0.05230	0.9672	0.684

Table B.2 (Continued)

T (K)	ρ (kg/m^3)	c_p (Ws/kg·K)	μ (kg/ms)	ν (m^2/s)	k (W/m·K)	α (m^2/s)	Pr
			Air *(Continued)*				
750	0.4709	1.0856	3.481	73.91	0.05509	1.0774	0.686
800	0.4405	1.0978	3.625	82.29	0.05779	1.1951	0.689
850	0.4149	1.1095	3.765	90.75	0.06028	1.3097	0.692
900	0.3925	1.1212	3.899	99.3	0.06279	1.4271	0.696
950	0.3716	1.1321	4.023	108.2	0.06525	1.5510	0.699
1000	0.3524	1.1417	4.152	117.8	0.06752	1.6779	0.702
1100	0.3204	1.160	4.44	138.6	0.0732	1.969	0.704
1200	0.2947	1.179	4.69	159.1	0.0782	2.251	0.707
1300	0.2707	1.197	4.93	182.1	0.0837	2.583	0.705
1400	0.2515	1.214	5.17	205.5	0.0891	2.920	0.705
1500	0.2355	1.230	5.40	229.1	0.0946	3.266	0.705
1600	0.2211	1.248	5.63	254.5	0.100	3.624	0.705
1700	0.2082	1.267	5.85	280.9	0.105	3.977	0.705
1800	0.1970	1.287	6.07	308.1	0.111	4.379	0.704
1900	0.1858	1.309	6.29	338.5	0.117	4.811	0.704
2000	0.1762	1.338	6.50	369.0	0.124	5.260	0.702
2100	0.1682	1.372	6.72	399.6	0.131	5.680	0.703
2200	0.1602	1.419	6.93	432.6	0.139	6.115	0.707
2300	0.1538	1.482	7.14	464.0	0.149	6.537	0.710
2400	0.1458	1.574	7.35	504.0	0.161	7.016	0.718
2500	0.1394	1.688	7.57	543.0	0.175	7.437	0.730
			Helium				
144	0.3379	5.200	125.5×10^{-7}	37.11×10^{-6}	0.0928	0.5275×10^{-4}	0.70
200	0.2435	5.200	156.6	64.38	0.1177	0.9288	0.694
255	0.1906	5.200	181.7	95.50	0.1357	1.3675	0.70
366	0.13280	5.200	230.5	173.6	0.1691	2.449	0.71
477	0.10204	5.200	275.0	269.3	0.197	3.716	0.72
589	0.08282	5.200	311.3	375.8	0.225	5.215	0.72
700	0.07032	5.200	347.5	494.2	0.251	6.661	0.72
800	0.06023	5.200	381.7	634.1	0.275	8.774	0.72
			Hydrogen				
150	0.16371	12.602	5.595×10^{-6}	34.18×10^{-5}	0.0981	0.475×10^{-4}	0.718
200	0.12270	13.540	6.813	55.53	0.1282	0.772	0.719
250	0.09819	14.059	7.919	80.64	0.1561	1.130	0.713
300	0.08185	14.314	8.963	109.5	0.182	1.554	0.706
350	0.07016	14.436	9.954	141.9	0.206	2.031	0.697
400	0.06135	14.491	10.864	177.1	0.228	2.568	0.690
450	0.05462	14.499	11.779	215.6	0.251	3.164	0.682
500	0.04918	14.507	12.636	257.0	0.272	3.817	0.675
550	0.04469	14.532	13.475	301.6	0.292	4.516	0.668
600	0.04085	14.537	14.285	349.7	0.315	5.306	0.664
700	0.03492	14.574	15.89	455.1	0.351	6.903	0.659
800	0.03060	14.675	17.40	569	0.384	8.563	0.664
900	0.02723	14.821	18.78	690	0.412	10.217	0.676
			Oxygen				
150	2.6190	0.9178	11.490×10^{-6}	4.387×10^{-6}	0.01367	0.05688×10^{-4}	0.773
200	1.9559	0.9131	14.850	7.593	0.01824	0.10214	0.745
250	1.5618	0.9157	17.87	11.45	0.02259	0.15794	0.725
300	1.3007	0.9203	20.63	15.86	0.02676	0.22353	0.709
350	1.1133	0.9291	23.16	20.80	0.03070	0.2968	0.702
400	0.9755	0.9420	25.54	26.18	0.03461	0.3768	0.695
450	0.8682	0.9567	27.77	31.99	0.03828	0.4609	0.694
500	0.7801	0.9722	29.91	38.34	0.04173	0.5502	0.697
550	0.7096	0.9881	31.97	45.05	0.04517	0.6441	0.700

Table B.2 *(Continued)*

T (K)	ρ (kg/m^3)	c_p, (Ws/kg·K)	μ (kg/ms)	ν (m^2/s)	k (W/m·K)	α (m^2/s)	Pr
			Nitrogen				
200	1.7108	1.0429	12.947×10^{-6}	7.568×10^{-6}	0.01824	0.10224×10^{-4}	0.747
300	1.1421	1.0408	17.84	15.63	0.02620	0.22044	0.713
400	0.8538	1.0459	21.98	25.74	0.03335	0.3734	0.691
500	0.6824	1.0555	25.70	37.66	0.03984	0.5530	0.684
600	0.5687	1.0756	29.11	51.19	0.04580	0.7486	0.686
700	0.4934	1.0969	32.13	65.13	0.05123	0.9466	0.691
800	0.4277	1.1225	34.84	81.46	0.05609	1.1685	0.700
900	0.3796	1.1464	37.49	91.06	0.06070	1.3946	0.711
1000	0.3412	1.1677	40.00	117.2	0.06475	1.6250	0.724
1100	0.3108	1.1857	42.28	136.0	0.06850	1.8591	0.736
1200	0.2851	1.2037	44.50	156.1	0.07184	2.0932	0.748
			Carbon dioxide				
220	2.4733	0.783	11.105×10^{-6}	4.490×10^{-6}	0.010805	0.05920×10^{-4}	0.818
250	2.1657	0.804	12.590	5.813	0.012884	0.07401	0.793
300	1.7973	0.871	14.958	8.321	0.016572	0.10588	0.770
350	1.5362	0.900	17.205	11.19	0.02047	0.14808	0.755
400	1.3424	0.942	19.32	14.39	0.02461	0.19463	0.738
450	1.1918	0.980	21.34	17.90	0.02897	0.24813	0.721
500	1.0732	1.013	23.26	21.67	0.03352	0.3084	0.702
550	0.9739	1.047	25.08	25.74	0.03821	0.3750	0.685
600	0.8938	1.076	26.83	30.02	0.04311	0.4483	0.668
			Ammonia, NH3				
273	0.7929	2.177	9.353×10^{-6}	1.18×10^{-5}	0.0220	0.1308×10^{-4}	0.90
323	0.6487	2.177	11.035	1.70	0.0270	0.1920	0.88
373	0.5590	2.236	12.886	2.30	0.0327	0.2619	0.87
423	0.4934	2.315	14.672	2.97	0.0391	0.3432	0.87
473	0.4405	2.395	16.49	3.74	0.0467	0.4421	0.84
			Water vapor				
380	0.5863	2.060	12.71×10^{-6}	2.16×10^{-5}	0.0246	0.2036×10^{-4}	1.060
400	0.5542	2.014	13.44	2.42	0.0261	0.2338	1.040
450	0.4902	1.980	15.25	3.11	0.0299	0.307	1.010
500	0.4405	1.985	17.04	3.86	0.0339	0.387	0.996
550	0.4005	1.997	18.84	4.70	0.0379	0.475	0.991
600	0.3652	2.026	20.67	5.66	0.0422	0.573	0.986
650	0.3380	2.056	22.47	6.64	0.0464	0.666	0.995
700	0.3140	2.085	24.26	7.72	0.0505	0.772	1.000
750	0.2931	2.119	26.04	8.88	0.0549	0.883	1.005
800	0.2739	2.152	27.86	10.20	0.0592	1.004	1.010
850	0.2579	2.186	29.69	11.52	0.0637	1.130	1.019

Table B.3 ***Approximate Properties of Common Liquids at Standard Atmospheric Pressure*** [3]

	English (FSS) Units						
	Temperature, T (°F)	Density, ρ (slug/ft^3)	Specific Gravity, s.g.	Modulus of Elasticity, K (psi)	Viscosity, $\mu \times 10^5$ (lb-s/ft^2)	Surface Tension, σ (lb/ft)	Vapor Pressure, ρ_v (psia)
Benzene	68	1.70	0.88	150,000	1.37	0.0020	1.45
Carbon tetrachloride	68	3.08	1.59	160,000	2.035	0.0018	1.90
Crude oil	68	1.66	0.86	—	15.0	0.002	—
Ethyl alcohol	68	1.53	0.79	175,000	2.51	0.0015	0.85
Freon-12	60	2.61	1.35	—	3.10	—	—
	–30	2.91	—	—	3.82	—	—
Gasoline	68	1.32	0.68	—	0.61	—	8.0
Glycerin	68	2.44	1.26	630,000	3,120	0.0043	0.000002
Hydrogen	–431	0.143	—	—	0.0435	0.0002	3.1
Jet fuel (JP-4)	60	1.50	0.77	—	1.82	0.002	1.3
Mercury	60	26.3	13.57	3,800,000	3.26	0.035	0.000025
	600	24.9	12.8	—	1.88	—	6.85
Oxygen	–320	2.34	—	—	0.58	0.001	3.1
Sodium	600	1.70	—	—	0.690	—	—
	1000	1.60	—	—	0.472	—	—
Water	68	1.936	1.00	318,000	2.10	0.0050	0.34

	SI Units						
	T (°C)	ρ (kg/m^3)	s.g.	K (kPa)	$\mu \times 10^4$ (Pa·s)	σ (N/m)	ρ_v (kPa)
Benzene	20	876.2	0.88	1,034,250	6.56	0.029	10.0
Carbon tetrachloride	20	1,587.4	1.59	1,103,200	9.74	0.026	13.1
Crude oil	20	855.6	0.86	—	71.8	0.03	—
Ethyl alcohol	20	788.6	0.79	1,206,625	12.0	0.022	5.86
Freon-12	15.6	1,345.2	1.35	—	14.8	—	—
	–34.4	1,499.8	—	—	18.3	—	—
Gasoline	20	680.3	0.68	—	2.9	—	55.2
Glycerin	20	1,257.6	1.26	4,343,850	14,939	0.063	0.000014
Hydrogen	–257.2	73.7	—	—	0.21	0.0029	21.4
Jet fuel (JP-4)	15.6	773.1	0.77	—	8.7	0.029	8.96
Mercury	15.6	13,555	13.57	26,201,000	15.6	0.51	0.00017
	315.6	12,833	12.8	—	9.0	—	47.2
Oxygen	–195.6	1,206.0	—	—	2.78	0.015	21.4
Sodium	315.6	876.2	—	—	3.30	—	—
	537.8	824.6	—	—	2.26	—	—
Water	20	998.2	1.00	2,170,500	10.0	0.073	2.34

Table B.4 *Properties of Water*[5]

T (°F)	T (°C)	c_p (kJ/kg·°C)	ρ (kg/m^3)	μ (kg/m·s)	k (W/m·°C)	Pr	$\frac{g\beta\rho^2 c_p}{\mu k}$[a] (1/m^3·°C)
32	0	4.225	999.8	1.79×10^{-3}	0.566	13.25	1.91×10^{9}
40	4.44	4.208	999.8	1.55	0.575	11.35	6.34×10^{9}
50	10	4.195	999.2	1.31	0.585	9.40	1.08×10^{10}
60	15.56	4.186	998.6	1.12	0.595	7.88	1.46×10^{10}
70	21.11	4.179	997.4	9.8×10^{-4}	0.604	6.78	1.91×10^{10}
80	26.67	4.179	995.8	8.6	0.614	5.85	2.48×10^{10}
90	32.22	4.174	994.9	7.65	0.623	5.12	3.3×10^{10}
100	37.78	4.174	993.0	6.82	0.630	4.53	4.19×10^{10}
110	43.33	4.174	990.6	6.16	0.637	4.04	4.89×10^{10}
120	48.89	4.174	988.8	5.62	0.644	3.64	5.66×10^{10}
130	54.44	4.179	985.7	5.13	0.649	3.30	6.48×10^{10}
140	60	4.179	983.3	4.71	0.654	3.01	7.62×10^{10}
150	65.55	4.183	980.3	4.3	0.659	2.73	8.84×10^{10}
160	71.11	4.186	977.3	4.01	0.665	2.53	9.85×10^{10}
170	76.67	4.191	973.7	3.72	0.668	2.33	1.09×10^{11}
180	82.22	4.195	970.2	3.47	0.673	2.16	
190	87.78	4.199	966.7	3.27	0.675	2.03	
200	93.33	4.204	963.2	3.06	0.678	1.90	
220	104.4	4.216	955.1	2.67	0.684	1.66	
240	115.6	4.229	946.7	2.44	0.685	1.51	
260	126.7	4.250	937.2	2.19	0.685	1.36	
280	137.8	4.271	928.1	1.98	0.685	1.24	
300	148.9	4.296	918.0	1.86	0.684	1.17	
350	176.7	4.371	890.4	1.57	0.677	1.02	
400	204.4	4.467	859.4	1.36	0.665	1.00	
450	232.2	4.585	825.7	1.20	0.646	0.85	
500	260	4.731	785.2	1.07	0.616	0.83	
550	287.7	5.024	735.5	9.51×10^{-5}			
600	315.6	5.703	678.7	8.68			

[a] $\mathrm{Gr}_x \mathrm{Pr} = \left(\frac{g\beta\rho^2 c_p}{\mu k}\right)\Delta T$

Table B.5 *Properties of Saturated Liquids*[4]

t (°C)	ρ (kg/m³)	c_p (kJ/kg·°C)	ν (m²/s)	k (W/m·°C)	α (m²/s)	Pr	β (K⁻¹)
Ammonia, NH^3							
–50	703.69	4.463	0.435×10^{-6}	0.547	1.742×10^{-7}	2.60	
–40	691.68	4.467	0.406	0.547	1.775	2.28	
–30	679.34	4.476	0.387	0.549	1.801	2.15	
–20	666.69	4.509	0.381	0.547	1.819	2.09	
–10	653.55	4.564	0.378	0.543	1.825	2.07	
0	640.10	4.635	0.373	0.540	1.819	2.05	
10	626.16	4.714	0.368	0.531	1.801	2.04	
20	611.75	4.798	0.359	0.521	1.775	2.02	2.45×10^{-3}
30	596.37	4.890	0.349	0.507	1.742	2.01	
40	580.99	4.999	0.340	0.493	1.701	2.00	
50	564.33	5.116	0.330	0.476	1.654	1.99	
Carbon dioxide, CO_2							
–50	1,156.34	1.84	0.119×10^{-6}	0.0855	0.4021×10^{-7}	2.96	
–40	1,117.77	1.88	0.118	0.1011	0.4810	2.46	
–30	1,076.76	1.97	0.117	0.1116	0.5272	2.22	
–20	1,032.39	2.05	0.115	0.1151	0.5445	2.12	
–10	983.38	2.18	0.113	0.1099	0.5133	2.20	
0	926.99	2.47	0.108	0.1045	0.4578	2.38	
10	860.03	3.14	0.101	0.0971	0.3608	2.80	
20	772.57	5.0	0.091	0.0872	0.2219	4.10	14.00×10^{-3}
30	597.81	36.4	0.080	0.0703	0.279	28.7	
Sulfur dioxide, SO_2							
–50	1,560.84	1.3595	0.484×10^{-6}	0.242	1.141×10^{-7}	4.24	
–40	1,536.81	1.3607	0.424	0.235	1.130	3.74	
–30	1,520.64	1.3616	0.371	0.230	1.117	3.31	
–20	1,488.60	1.3624	0.324	0.225	1.107	2.93	
–10	1,463.61	1.3628	0.288	0.218	1.097	2.62	
0	1,438.46	1.3636	0.257	0.211	1.081	2.38	
10	1,412.51	1.3645	0.232	0.204	1.066	2.18	
20	1,386.40	1.3653	0.210	0.199	1.050	2.00	1.94×10^{-3}
30	1,359.33	1.3662	0.190	0.192	1.035	1.83	
40	1,329.22	1.3674	0.173	0.185	1.019	1.70	
50	1,299.10	1.3683	0.162	0.177	0.999	1.61	
Dichlorodifluoromethane (freon), CCl_2F_2							
–50	1,546.75	0.8750	0.310×10^{-6}	0.067	0.501×10^{-7}	6.2	2.63×10^{-3}
–40	1,518.71	0.8847	0.279	0.069	0.514	5.4	
–30	1,489.56	0.8956	0.253	0.069	0.526	4.8	
–20	1,460.57	0.9073	0.235	0.071	0.539	4.4	
–10	1,429.49	0.9203	0.221	0.073	0.550	4.0	
0	1,397.45	0.9345	0.214	0.073	0.557	3.8	
10	1,364.30	0.9496	0.203	0.073	0.560	3.6	
20	1,330.18	0.9659	0.198	0.073	0.560	3.5	
30	1,295.10	0.9835	0.194	0.071	0.560	3.5	
40	1,257.13	1.0019	0.191	0.069	0.555	3.5	
50	1,215.96	1.0216	0.190	0.067	0.545	3.5	
Glycerin, $C_3H_5(OH)_3$							
0	1,276.03	2.261	0.00831	0.282	0.983×10^{-7}	84.7×10^3	
10	1,270.11	2.319	0.00300	0.284	0.965	31.0	
20	1,264.02	2.386	0.00118	0.286	0.947	12.5	0.50×10^{-3}
30	1,258.09	2.445	0.00050	0.286	0.929	5.38	
40	1,252.01	2.512	0.00022	0.286	0.914	2.45	
50	1,244.96	2.583	0.00015	0.287	0.893	1.63	

Table B.5 *(Continued)*

t (°C)	ρ (kg/m³)	c_p (kJ/kg·°C)	ν (m²/s)	k (W/m·°C)	α (m²/s)	Pr	β (K⁻¹)
Ethylene glycol, $C_2H_4(OH)_2$							
0	1,130.75	2.294	57.53×10^{-6}	0.242	0.934×10^{-7}	615	
20	1,116.65	2.382	19.18	0.249	0.939	204	0.65×10^{-3}
40	1,101.43	2.474	8.69	0.256	0.939	93	
60	1,087.66	2.562	4.75	0.260	0.932	51	
80	1,077.56	2.650	2.98	0.261	0.921	32.4	
100	1,058.50	2.742	2.03	0.263	0.908	22.4	
Engine oil (unused)							
0	899.12	1.796	0.00428	0.147	0.911×10^{-7}	47,100	
20	888.23	1.880	0.00090	0.145	0.872	10,400	0.70×10^{-3}
40	876.05	1.964	0.00024	0.144	0.834	2,870	
60	864.04	2.047	0.839×10^{-4}	0.140	0.800	1,050	
80	852.02	2.131	0.375	0.138	0.769	490	
100	840.01	2.219	0.203	0.137	0.738	276	
120	828.96	2.307	0.124	0.135	0.710	175	
140	816.94	2.395	0.080	0.133	0.686	116	
160	805.89	2.483	0.056	0.132	0.663	84	
Mercury, Hg							
0	13,628.22	0.1403	0.124×10^{-6}	8.20	42.99×10^{-7}	0.0288	
20	13,579.04	0.1394	0.114	8.69	46.06	0.0249	1.82×10^{-4}
50	13,505.84	0.1386	0.104	9.40	50.22	0.0207	
100	13,384.58	0.1373	0.0928	10.51	57.16	0.0162	
150	13,264.28	0.1365	0.0853	11.49	63.54	0.0134	
200	13,144.94	0.1570	0.0802	12.34	69.08	0.0116	
250	13,025.60	0.1357	0.0765	13.07	74.06	0.0103	
315.5	12,847	0.134	0.0673	14.02	81.5	0.0083	
Water, H_2O							
0	1,002.28	4.2178×10^{3}	1.788×10^{-6}	0.552	1.308×10^{-7}	13.6	0.18×10^{-3}
20	1,000.52	4.1818	1.006	0.597	1.430	7.02	
40	994.59	4.1784	0.658	0.628	1.512	4.34	
60	985.46	4.1843	0.478	0.651	1.554	3.02	
80	974.08	4.1964	0.364	0.668	1.636	2.22	
100	960.63	4.2161	0.294	0.680	1.680	1.74	
120	945.25	4.250	0.247	0.685	1.708	1.446	
140	928.27	4.283	0.214	0.684	1.724	1.241	
160	909.69	4.342	0.190	0.680	1.729	1.099	
180	889.03	4.417	0.173	0.675	1.724	1.004	
200	866.76	4.505	0.160	0.665	1.706	0.937	
220	842.41	4.610	0.150	0.652	1.680	0.891	
240	815.66	4.756	0.143	0.635	1.639	0.871	
260	785.87	4.949	0.137	0.611	1.577	0.874	
280.6	752.55	5.208	0.135	0.580	1.481	0.910	
300	714.26	5.728	0.135	0.540	1.324	1.019	

Table B.6 ***Properties of Metals***[4]

Metal	Properties at 20°C ρ (kg/m³)	c_p (kJ/kg·°C)	k (W/m·°C)	α (m²/s × 10⁵)	Thermal Conductivity k (W/m·°C) −100°C −148°F	0°C 32°F	100°C 212°F	200°C 392°F	300°C 572°F	400°C 752°F	600°C 1112°F	800°C 1472°F	1000°C 1832°F	1200°C 2192°F
Aluminum														
Pure	2,707	0.896	204	8.418	215	202	206	215	228	249				
Al-Cu (Duralumin) 94–96% Al, 3–5% CU, trace Mg	2,787	0.883	164	6.676	126	159	182	194						
Al-Si (Silumin, copper bearing) 86.5% Al, 1% Cu	2,659	0.867	137	5.933	119	137	144	152	161					
Al-Si (Alusil) 78–80% Al, 20–22% Si	2,627	0.854	161	7.172	144	157	168	175	178					
Al-Mg-Si 97% Al, 1% Mg, 1% Si, 1% Mn	2,707	0.892	177	7.311		175	189	204						
Lead	11,373	0.130	35	2.343	36.9	35.1	33.4	31.5	29.8					
Iron														
Pure	7,897	0.452	73	2.034	87	73	67	62	55	48	40	36	35	36
Wrought iron 0.5% C	7,849	0.46	59	1.626		59	57	52	48	45	36	33	33	33
Steel (C max ≈ 1.5%): Carbon steel														
C ≈ 0.5%	7,833	0.465	54	1.474		55	52	48	45	42	35	31	29	31
1.0%	7,801	0.473	43	1.172		43	43	42	40	36	33	29	28	29
1.5%	7,753	0.486	36	0.970		36	36	36	35	33	31	28	28	29
Nickel steel														
Ni ≈ 0%	7,897	0.452	73	2.026										
20%	7,933	0.46	19	0.526										
40%	8,169	0.46	10	0.279										
80%	8,618	0.46	35	0.872										
Invar 36% Ni	8,137	0.46	10.7	0.286										
Chrome steel														
Cr = 0%	7,897	0.452	73	2.026	87	73	67	62	55	48	40	36	35	36
1%	7,865	0.46	61	1.665		62	55	52	47	42	36	33	33	
5%	7,833	0.46	40	1.110		40	38	36	36	33	29	29	29	
20%	7,689	0.46	22	0.635		22	22	22	22	24	24	26	29	
Cr-Ni, chrome-nickel 15% Cr, 10% Ni	7,865	0.46	19	0.526										
18% Cr, 8% Ni (V2A)	7,817	0.46	16.3	0.444		16.3	17	17	19	19	22	26	31	
20% Cr, 15% Ni	7,833	0.46	15.1	0.415										
25% Cr, 20% Ni	7,865	0.46	12.8	0.361										
Tungsten steel														
W = 0%	7,897	0.452	73	2.026										
1%	7,913	0.448	66	1.858										
5%	8,073	0.435	54	1.525										
10%	8,314	0.419	48	1.391										

Table B.6 (Continued)

Metal	Properties at 20°C				Thermal Conductivity k (W/m·°C)									
	ρ (kg/m^3)	c_p (kJ/kg·°C)	k (W/m·°C)	α (m^2/s $\times$ 10^5)	–100°C –148°F	0°C 32°F	100°C 212°F	200°C 392°F	300°C 572°F	400°C 752°F	600°C 1112°F	800°C 1472°F	1000°C 1832°F	1200°C 2192°F
Copper														
Pure	8,954	0.3831	386	11.234	407	386	379	374	369	363	353			
Aluminum bronze 95% Cu, 5% Al	8,666	0.410	83	2.330										
Bronze 75% Cu, 25% Sn	8,666	0.343	26	0.859										
Red brass 85% Cu, 9% Sn, 6% Zn	8,714	0.385	61	1.804		59	71							
Brass 70% Cu, 30% Zn	8,522	0.385	111	3.412	88		128	144	147	147				
German silver 62% Cu, 15% Ni, 22% Zn	8,618	0.394	24.9	0.733	19.2		31	40	45	48				
Constantan 60% Cu, 40% Ni	8,922	0.410	22.7	0.612	21		22.2	26						
Magnesium														
Pure	1,746	1.013	171	9.708	178	171	168	163	157					
Mg-Al (electrolytic) 6–8% Al, 1–2% Zn	1,810	1.00	66	3.605	138	52	62	74	83					
Molybdenum	10,220	0.251	123	4.790		125	118	114	111	109	106	102	99	92
Nickel														
Pure (99.9%)	8,906	0.4459	90	2.266	104	93	83	73	64	59				
Ni-Cr 90% Ni, 10% Cr	8,666	0.444	17	0.444		17.1	18.9	20.9	22.8	24.6				
80% Ni, 20% Cr	8,314	0.444	12.6	0.343		12.3	13.8	15.6	17.1	18.0	22.5			
Silver														
Purest	10,524	0.2340	419	17.004	419	417	415	412						
Pure (99.9%)	10,524	0.2340	407	16.563	419	410	415	374	362	360				
Tin, pure	7,304	0.2265	64	3.884	74	65.9	59	57						
Tungsten	19,350	0.1344	163	6.271		166	151	142	133	126	112	76		
Zinc, pure	7,144	0.3843	112.2	4.106	114	112	109	106	100	93				

Table B.7 *Properties of Nonmetals*[5]

Substance	Temperature (°C)	k (W/m·°C)	ρ (kg/m³)	C (kJ/kg·°C)	α (m²/s × 10⁷)
Insulating material					
Asbestos					
Loosely packed	–45	0.149	470–570	0.816	3.3–4
	0	0.154			
	100	0.161			
Asbestos-cement boards	20	0.74			
Sheets	51	0.166			
Felt, 40 laminations/in.	38	0.057			
	150	0.069			
	260	0.083			
20 laminations/in.	38	0.078			
	150	0.095			
	260	0.112			
Corrugated, 4 plies/in.	38	0.087			
	93	0.100			
	150	0.119			
Asbestos cement	—	2.08			
Balsam wool, 2.2 lb/ft³	32	0.04	35		
Cardboard, corrugated	—	0.064			
Celotex	32	0.048			
Corkboard, 10 lb/ft³	30	0.043	160		
Cork, regranulated	32	0.045	45–120	1.88	2–5.3
Ground	32	0.043	150		
Diatomaceous earth (Sil-o-cel)	0	0.061	320		
Felt, hair	30	0.036	130–200		
Wool	30	0.052	330		
Fiber, insulating board	20	0.048	240		
Glass wool, 1.5 lb/ft³	23	0.038	24	0.7	22.6
Insulex, dry	32	0.064			
		0.144			
Kapok	30	0.035			
Magnesia, 85%	38	0.067	270		
	93	0.071			
	150	0.074			
	204	0.080			
Rock wool, 10 lb/ft³	32	0.040	160		
Loosely packed	150	0.067	64		
	260	0.087			
Sawdust	23	0.059			
Silica aerogel	32	0.024	140		
Wood shavings	23	0.059			
Structural and heat-resistant materials					
Asphalt	20–55	0.74–0.76			
Brick					
Building brick, common	20	0.69	1600	0.84	5.2
face		1.32	2000		
Carborundum brick	600	18.5			
	1400	11.1			
Chrome brick	200	2.32	3000	0.84	9.2
	550	2.47			9.8
	900	1.99			7.9
Diatomaceous earth, molded and fired	200	0.24			
	870	0.31			
Fireclay brick, burnt 2426°F	500	1.04	2000	0.96	5.4
	800	1.07			
	1100	1.09			

Table B.7 ***(Continued)***

Substance	Temperature (°C)	*k* (W/m·°C)	ρ (kg/m³)	*C* (kJ/kg·°C)	α (m²/s × 10⁷)
		Insulating material			
Brick, continued					
Fireclay brick, burnt 2642°F	500	1.28	2300	0.96	5.8
	800	1.37			
	1100	1.40			
Missouri	200	1.00	2600	0.96	4.0
	600	1.47			
	1400	1.77			
Magnesite	200	3.81		1.13	
	650	2.77			
	1200	1.90			
Cement, portland		0.29	1500		
Mortar	23	1.16			
Concrete, cinder	23	0.76			
Stone 1-2-4 mix	20	1.37	1900–2300	0.88	8.2–6.8
Glass, window	20	0.78 (avg)	2700	0.84	3.4
Corosilicate	30–75	1.09	2200		
Plaster, gypsum	20	0.48	1440	0.84	4.0
Metal lath	20	0.47			
Wood lath	20	0.28			
Stone					
Granite		1.73–3.98	2640	0.82	8–18
Limestone	100–300	1.26–1.33	2500	0.90	5.6–5.9
Marble		2.07–2.94	2500–2700	0.80	10–13.6
Sandstone	40	1.83	2160–2300	0.71	11.2–11.9
Wood (across the grain)					
Balsa 8.8 lb/ft³	30	0.055	140		
Cypress	30	0.097	460		
Fir	23	0.11	420	2.72	0.96
Maple or oak	30	0.166	540	2.4	1.28
Yellow pine	23	0.147	640	2.8	0.82
White pine	30	0.112	430		

APPENDIX C

Fuel Properties and Combustion Data

Table C.1 *Physical and Combustion Properties of Selected Fuels in Air*[6]

Fuel	Mol. wt.	Spec. grav.	T_{Boil} (°C)	Heat of vap. (kJ/kg)	Heat of comb. (mJ/kg)	Stoichiometry % Vol.	Stoichiometry f^a	Flammability Limits (% stoichio.) Lean	Flammability Limits (% stoichio.) Rich	Spont. Ign. Temp. (°C)	Fuel for Max. Flame Speed (% stoichio.)	Max. Flame Speed (cm/s)	Flame Temp. at Max. Fl. Speed K	Ign. Energy Stoich. (10^{-5} cal.)	Ign. Energy Min. (10^{-5} cal.)	Quenching Dist. Stoich. (mm)	Quenching Dist. Min. (mm)
Acetaldehyde	44.1	0.783	–56.7	569.4	—	0.0772	0.1280	—	—	—	—	—	—	8.99	—	2.29	—
Acetone	58.1	0.792	56.7	523.0	30.8	0.0497	0.1054	59	233	561.1	131	50.18	2121	27.48	—	3.81	—
Acetylene	26.0	0.621	–83.9	—	48.2	0.0772	0.0755	31	—	305.0	133	155.25	—	0.72	—	0.76	—
Acrolein	56.1	0.841	52.8	—	—	0.0564	0.1163	48	752	277.8	100	61.75	—	4.18	—	1.52	—
Acrylonitrile	53.1	0.797	78.3	—	—	0.0528	0.1028	87	—	481.1	105	46.75	2461	8.60	3.82	2.29	1.52
Ammonia	17.0	0.817	–33.3	1373.6	—	0.2181	0.1645	—	—	651.1	—	—	2600	—	—	—	—
Aniline	93.1	1.022	184.4	432.6	—	0.0263	0.0872	—	—	593.3	—	—	—	—	—	—	—
Benzene	78.1	0.885	80.0	431.8	39.9	0.0277	0.0755	43	336	591.7	108	44.60	2365	13.15	5.38	2.79	1.78
Benzyl alcohol	108.1	1.050	205.0	—	—	0.0240	0.0923	—	—	427.8	—	—	—	—	—	—	—
1,2-Butadiene (methylallene)	54.1	0.658	11.1	—	45.5	0.0366	0.0714	—	—	—	117	63.90	2419	5.60	—	1.30	—
n-Butane	58.1	0.584	–0.5	385.8	45.7	0.0312	0.0649	54	330	430.6	113	41.60	2256	18.16	6.21	3.05	1.78
Butanone (methylethyl ketone)	72.1	0.805	79.4	—	—	0.0366	0.0951	—	—	—	100	39.45	—	12.67	6.69	2.54	2.03
1-Butene	56.1	0.601	–6.1	443.9	45.3	0.0377	0.0678	53	353	443.3	116	47.60	2319	—	—	—	—
d-Camphor	152.2	0.990	203.4	—	—	0.0153	0.0818	—	—	466.1	—	—	—	—	—	—	—
Carbon disulfide	76.1	1.263	46.1	351.0	—	0.0652	0.1841	18	1120	120.0	102	54.46	—	0.36	—	0.51	—
Carbon monoxide	28.0	—	–190.0	211.7	—	0.2950	0.4064	34	676	608.9	170	42.88	—	—	—	—	—
Cyclobutane	56.1	0.703	12.8	—	—	0.0377	0.0678	—	—	—	115	62.18	2308	—	—	—	—
Cyclohexane	84.2	0.783	80.6	258.1	43.8	0.0227	0.0678	48	401	270.0	117	42.46	2250	32.98	5.33	4.06	1.78
Cyclohexene	82.1	0.810	82.8	—	—	0.0240	0.0701	—	—	—	—	44.17	—	20.55	—	3.30	—
Cyclopentane	70.1	0.751	49.4	388.3	44.2	0.0271	0.0678	—	—	385.0	117	41.17	2264	19.84	—	3.30	—
Cyclopropane	42.1	0.720	–34.4	—	—	0.0444	0.0678	58	276	497.8	113	52.32	2328	5.74	5.50	1.78	1.78
trans-Decalin	138.2	0.874	187.2	—	—	0.0142	0.0692	—	—	271.7	109	33.88	2222	—	—	—	—
n-Decane	142.3	0.734	174.0	359.8	44.2	0.0133	0.0666	45	356	231.7	105	40.31	2286	—	—	2.06	—
Diethyl ether	74.1	0.714	34.4	351.6	—	0.0337	0.0896	55	2640	185.6	115	43.74	2253	11.71	6.69	2.54	2.03
Ethane	30.1	—	–88.9	488.3	47.4	0.0564	0.0624	50	272	472.2	112	44.17	2244	10.04	5.74	2.29	1.78
Ethyl acetate	88.1	0.901	77.2	—	—	0.0402	0.1279	61	236	486.1	100	35.59	—	33.94	11.47	4.32	2.54
Ethanol	46.1	0.789	78.5	836.8	26.8	0.0652	0.1115	—	—	392.2	—	—	—	—	—	—	—
Ethylamine	45.1	0.706	16.7	611.3	—	0.0528	0.0873	—	—	—	—	—	—	57.36	—	5.33	—
Ethylene oxide	44.1	1.965	10.6	581.1	—	0.0772	0.1280	—	—	428.9	125	11.35	2411	2.51	1.48	1.27	1.02
Furan	68.1	0.936	32.2	400.0	—	0.0444	0.1098	—	—	—	—	—	—	5.40	—	1.78	—
n-Heptane	100.2	0.688	98.5	364.9	44.4	0.0187	0.0661	53	450	247.2	122	42.46	2214	27.49	5.74	3.81	1.78
n-Hexane	86.2	0.664	68.0	364.9	44.7	0.0216	0.0659	51	400	260.6	117	42.46	2239	22.71	5.50	3.56	1.78
Hydrogen	2.0	—	–252.7	451.0	119.9	0.2950	0.0290	—	—	571.1	170	291.19	2380	0.36	0.36	0.51	0.51
iso-Propanol	60.1	0.785	82.2	664.8	—	0.0444	0.0969	—	—	455.6	100	38.16	—	15.54	—	2.79	—
Kerosene	154.0	0.825	250.0	290.8	43.1	—	—	—	—	—	—	—	—	—	—	—	—
Methane	16.0	—	–161.7	509.2	50.0	0.0947	0.0581	46	164	632.2	106	37.31	2236	7.89	6.93	2.54	2.03
Methanol	32.0	0.793	64.5	1100.9	19.8	0.1224	0.1548	48	408	470.0	101	52.32	—	5.14	3.35	1.78	1.52
Methyl formate	60.1	0.975	31.7	472.0	—	0.0947	0.2181	—	—	—	—	—	—	14.82	—	2.79	—
n-Nonane	128.3	0.772	150.6	288.3	44.6	0.0147	0.0665	47	434	238.9	—	—	—	—	—	—	—

Table C.1 ***(Continued)***

Fuel	Mol. wt.	Spec. grav.	T_{Boil} (°C)	Heat of vap. (kJ/kg)	Heat of comb. (mJ/kg)	Stoichiometry % Vol.	Stoichiometry f^a	Flammability Limits (% stoichio.) Lean	Flammability Limits (% stoichio.) Rich	Spont. Ign. Temp. (°C)	Fuel for Max. Flame Speed (% stoichio.)	Max. Flame Speed (cm/s)	Flame Temp. at Max. Fl. Speed K	Ign. Energy Stoich. (10^{-5} cal.)	Ign. Energy Min. (10^{-5} cal.)	Quenching Dist. Stoich. (mm)	Quenching Dist. Min. (mm)
n-Octane	114.2	0.707	125.6	300.0	44.8	0.0165	0.0633	51	425	240.0	—	—	2251	—	—	—	—
n-Pentane	72.1	0.631	36.0	364.4	45.3	0.0255	0.0654	54	359	284.4	115	42.46	2250	19.60	5.26	3.30	1.78
1-Pentene	70.1	0.646	30.0	—	45.0	0.0271	0.0678	47	370	298.3	114	46.75	2314	—	—	—	—
Propane	44.1	0.508	–42.2	425.5	46.3	0.0402	0.0640	51	283	504.4	114	42.89	2250	7.29	—	2.03	1.78
Propene	42.1	0.522	–47.7	437.2	45.8	0.0444	0.0678	48	272	557.8	114	48.03	2339	6.74	—	2.03	—
n-Propanol	60.1	0.804	97.2	685.8	—	0.0444	0.0969	—	—	433.3	—	—	—	—	—	—	—
Toulene	92.1	0.872	110.6	362.8	40.9	0.0227	0.0743	43	322	567.8	105	38.60	2344	—	—	—	—
Triethylamine	101.2	0.723	89.4	—	—	0.0210	0.0753	—	—	—	—	—	—	27.48	—	3.81	—
Turpentine	—	—	—	—	—	—	—	—	—	252.2	—	—	—	—	—	—	—
Xylene	106.0	0.870	130.0	334.7	43.1	—	—	—	—	—	—	—	—	—	—	—	—
Gasoline 73 octane	120.0	0.720	155.0	338.9	44.1	—	—	—	—	298.9	—	—	—	—	—	—	—
Gasoline 100 octane	—	—	—	—	—	—	—	—	—	468.3	106	37.74	—	—	—	—	—
Jet fuel JP1	150.0	0.810	—	—	43.0	0.0130	0.0680	—	—	248.9	107	36.88	—	—	—	—	—
JP3	112.0	0.760	—	—	43.5	0.0170	0.0680	—	—	—	—	—	—	—	—	—	—
JP4	126.0	0.780	—	—	43.5	0.0150	0.0680	—	—	261.1	107	38.17	—	—	—	—	—
JP5	170.0	0.830	—	—	43.0	0.0110	0.0690	—	—	242.2	—	—	—	—	—	—	—

[a] f is the stoichiometric air/fuel ratio; i.e., $f = {}^{1}/_{r}$.

Table C.2 *Heats of Combustion and Related Properties of Pure Substances*[7]

Material	Composition	Molecular Weight, W	Gross, Δh_c^u (MJ/kg)	Net, Δh_c^l (MJ/kg)	$\Delta h_c^l/r_o$ (MJ/kg O_2)	Oxygen Fuel Mass Ratio, r_o	Boiling Temp., T_b (°C)	Latent Heat of Vaporization, Δh_v (kJ/kg)	Liquid Heat Capacity, C_{pl} (kJ/kg·°C)	Vapor Heat Capacity, C_{pv} (kJ/kg·°C)
Acetaldehyde	C_2H_4O	44.05	27.07	25.07	13.81	1.816	20.8	—	1.94	1.24
Acetic acid	$C_2H_4O_2$	60.05	14.56	13.09	12.28	1.066	118.1	395		1.11
Acetone	C_3H_6O	58.08	30.83	28.56	12.96	2.204	56.5	501	2.12	1.29
Acetylene	C_2H_2	26.04	49.91	48.22	15.70	3.072	–84.0	—	—	1.69
Acrolein	C_3H_4O	56.06	29.08	27.51	13.77	1.998	52.5	505	—	1.17
Acrylonitrile	C_3H_3N	53.06	33.16	31.92	14.11	2.262	77.3	615	2.10	1.20
(Allene) → propadiene										
Ammonium perchlorate[a]	NH_4ClO_4	117.49	2.35	2.16	3.97	0.545	—	—	—	
iso-Amyl alcohol	$C_5H_{12}O$	88.15	37.48	34.49	12.67	2.723	132.0	501	2.90	1.50
Aniline	C_6H_7N	93.12	36.44	34.79	13.06	2.663	184.4	478	2.08	1.16
Benzaldehyde	C_7H_6O	106.12	33.25	32.01	13.27	2.412	179.2	385	1.61	
Benzene	C_6H_6	78.11	41.83	40.14	13.06	3.073	80.1	389	1.72	1.05
Benzoic acid[a]	$C_7H_6O_2$	122.12	26.43	25.35	12.90	1.965	250.8	415	—	0.85
Benzyl alcohol	C_7H_8O	108.13	34.56	32.93	13.09	2.515	205.7	467	2.00	1.19
Bicyclohexyl	$C_{12}H_{22}$	166.30	45.35	42.44	12.61	3.367	236.0	263		
1,2-Butadiene	C_4H_6	54.09	47.95	45.51	13.99	3.254	10.8	—	—	1.48
1,3-Butadiene	C_4H_6	54.09	46.99	44.55	13.69	3.254	–4.4	—	—	1.47
(1,3-Butadiyne) → diacetylene										
n-Butane	C_4H_{10}	58.12	49.50	45.72	12.77	3.579	–0.5	—	2.30	1.68
iso-Butane	C_4H_{10}	58.12	48.95	45.17	12.62	3.579	–11.8	—	—	1.67
1-Butene	C_4H_8	56.10	48.44	45.31	13.24	3.422	–6.2	—	—	1.53
n-Butylamine	$C_4H_{11}N$	73.14	41.75	38.45	12.84	2.994	77.8	372	2.57	1.62
d-Camphor[a]	$C_{10}H_{16}O$	152.23	38.75	36.44	12.84	2.838	203.4	—	—	0.82
Carbon[a]	C	12.01	32.80	32.80	12.31	2.664	4200.0	—	—	0.71
Carbon disulfide	CS_2	76.13	6.34	6.34	5.03	1.261	46.5	351	1.00	0.60
Carbon monoxide	CO	28.01	10.10	10.10	17.69	0.571	–191.3	—	—	1.04
Cellulose[a]	$C_6H_{10}O_5$	162.14	17.47	16.12	13.61	1.184	—	—	1.16	—
(Chloroethylene) → vinyl chloride										
(Chloroform) → trichloromethane										
Chlorotrifluoroethylene	C_2F_3Cl	116.47	2.00	2.00	3.64	0.549	–28.3	188	1.34	0.72
m-Cresol	C_7H_8O	108.13	34.26	32.64	12.98	2.515	202.2	399	2.00	1.13
Cumene	C_9H_{12}	120.19	43.40	41.20	12.90	3.195	152.3	312	1.77	1.26
Cyanogen	C_2N_2	52.04	21.06	21.06	17.12	1.230	–21.2	—	—	1.12
Cyclobutane	C_4H_8	56.10	48.91	45.77	13.38	3.422	12.9	—	—	1.29
Cyclohexane	C_6H_{12}	84.16	46.58	43.45	12.70	3.422	80.7	357	1.84	1.26
Cyclohexene	C_6H_{10}	82.14	45.67	42.99	12.99	3.311	82.8	371	1.80	1.28
Cyclohexylamine	$C_6H_{13}N$	99.18	41.05	38.17	12.79	2.984	134.5			
Cyclopentane	C_5H_{10}	70.13	46.93	43.80	12.80	3.422	49.3	389	2.23	1.18
Cyclopropane	C_3H_6	42.08	49.70	46.57	13.61	3.422	–32.9	—	1.92	1.33
(Decahydronaphthalene) → *cis*-decalin										
cis-Decalin	$C_{10}H_{18}$	138.24	45.49	42.63	12.70	3.356	195.8	309	1.67	1.21
n-Decane	$C_{10}H_{22}$	142.28	47.64	44.24	12.69	3.486	174.1	276	2.19	1.85
Diacetylene	C_4H_2	50.06	46.60	45.72	15.89	2.877	10.3	—	—	1.47
(Diamine) → hydrazine										
Diborane	H_6B_2	27.69	79.80	79.80	23.02	3.467	–92.5	—	—	1.75
Dichloromethane	CH_2Cl_2	84.94	6.54	6.02	10.65	0.565	39.7	330	1.18	0.80
Diethyl cyclohexane	$C_{10}H_{20}$	140.26	46.30	43.17	12.58	3.422	174.0		1.87	
Diethyl ether	$C_4H_{10}O$	74.12	36.75	33.79	13.04	2.590	34.6	360	2.34	1.52
(2,4 Diisocyanotoulene) → toluene diisocyanate										
(Diisopropyl ether) → *iso*-propyl ether										
Dimethylamine	C_2H_7N	45.08	38.66	35.25	13.24	2.662	6.9	—	—	1.80
(Dimethyl aniline) → xylidene										
Dimethyldecalin	$C_{12}H_{22}$	166.30	45.70	42.79	13.15	3.254	220.0	260		
(Dimethyl ether) → methyl ether										
1,1-Dimethylhydrazine (UDMH)	$C_2H_8N_2$	60.10	32.95	30.03	14.10	2.130	25.0	578	2.73	
Dimethyl sulfoxide	C_2H_6SO	78.13	29.88	28.19	15.30	1.843	189.0	677	1.89	1.14
1,3 Dioxane	$C_4H_8O_2$	88.10	26.57	24.58	9.66	2.543	105.0	404		

Table C.2 *(Continued)*

Material	Composition	Molecular Weight, W	Gross, Δh_c^u (MJ/kg)	Net, Δh_c^l (MJ/kg)	$\Delta h_c^l/r_o$ (MJ/kg O_2)	Oxygen Fuel Mass Ratio, r_o	Boiling Temp., T_b (°C)	Latent Heat of Vaporization, Δh_v (kJ/kg)	Liquid Heat Capacity, C_{pl} (kJ/kg·°C)	Vapor Heat Capacity, C_{pv} (kJ/kg·°C)
1,4 Dioxane	$C_4H_8O_2$	88.10	26.83	24.84	9.77	2.543	101.1	406	1.74	1.07
Ethane	C_2H_6	30.07	51.87	47.49	12.75	3.725	–88.6	—	—	1.75
Ethanol	C_2H_6O	46.07	29.67	26.81	12.87	2.084	78.5	837	2.43	1.42
(Ethene) → ethylene										
Ethyl acetate	$C_4H_8O_2$	88.10	25.41	23.41	12.89	1.816	77.2	367	1.94	1.29
Ethyl acrylate	$C_5H_8O_2$	100.12	27.44	25.69	13.39	1.918	100.0	290		1.14
Ethylamine	C_2H_7N	45.08	38.63	35.22	13.23	2.662	16.5	—	2.89	1.61
Ethyl benzene	C_8H_{10}	106.16	43.00	40.93	12.93	3.165	136.1	339	1.75	1.21
Ethylene	C_2H_4	28.05	50.30	47.17	13.78	3.422	–103.9	—	2.38	1.56
Ethylene glycol	$C_2H_6O_2$	62.07	19.17	17.05	13.22	1.289	197.5	800	2.43	1.56
Ethylene oxide	C_2H_4O	44.05	29.65	27.65	15.23	1.816	10.7	—	1.97	1.10
(Ethylene trichloride) → trichloroethylene										
(Ethyl ether) → diethyl ether										
Formaldehyde	CH_2O	30.03	18.76	17.30	16.23	1.066	–19.3	—	—	1.18
Formic acid	CH_2O_2	46.03	5.53	4.58	13.15	0.348	100.5	476	2.15	0.98
Furan	C_4H_4O	68.07	30.61	29.32	13.86	2.115	31.4	398	1.69	0.96
a-D-glucose[a]	$C_6H_{12}O_6$	180.16	15.55	14.08	13.21	1.066	—	—	—	—
(Glycerine) → glycerol										
Glycerol	$C_3H_8O_3$	92.10	17.95	16.04	13.19	1.216	290.0	800	2.42	1.25
(Glycerol trinitrate) → nitroglycerin										
n-Heptane	C_7H_{16}	100.20	48.07	44.56	12.68	3.513	98.4	316	2.20	1.66
n-Heptene	C_7H_{14}	98.18	47.44	44.31	12.95	3.422	93.6	317	2.17	1.58
Hexadecane	$C_{16}H_{34}$	226.43	47.25	43.95	12.70	3.462	286.7	226	2.22	1.64
Hexamethyldisiloxane	$C_6H_{18}Si_2O$	162.38	38.30	35.80	15.16	2.364	100.1	192	2.01	—
(Hexamethylenetetramine) → methenamine										
n-Hexane	C_6H_{14}	86.17	48.31	44.74	12.68	3.528	68.7	335	2.24	1.66
n-Hexene	C_6H_{12}	84.16	47.57	44.44	12.99	3.422	63.5	333	2.18	1.57
Hydrazine	H_4N_2	32.05	52.08	49.34	49.40	0.998	113.5	1180	3.08	1.65
Hydrazoic acid	HN_3	43.02	15.28	14.77	79.40	0.186	35.7	690	—	1.02
Hydrogen	H_2	2.00	141.79	130.80	16.35	8.000	–252.7	—	—	14.42
(Hydrogen azide) → hydrazoic acid										—
Hydrogen cyanide	HCN	27.03	13.86	13.05	8.82	1.480	25.7	933	2.61	1.33
Hydrogen sulfide	H_2S	34.08	48.54	47.25	16.77	2.817	–60.3	548	—	1.00
Maleic anhydride[a]	$C_4H_2O_3$	74.04	18.77	18.17	14.01	1.297	202.0	—	—	—
Melamine[a]	$C_3H_6N_6$	126.13	15.58	14.54	12.73	1.142	—	—	—	—
Methane	CH_4	16.04	55.50	50.03	12.51	4.000	–161.5	—	—	2.23
Methanol	CH_4O	32.04	22.68	19.94	13.29	1.500	64.8	1101	2.37	1.37
Methenamine[a]	$C_6H_{12}N_4$	140.19	29.97	28.08	13.67	2.054	—	—	—	—
2-Methoxyethanol	$C_3H_8O_2$	76.09	24.23	21.92	13.03	1.682	124.4	583	2.23	—
Methylamine	CH_5N	31.06	34.16	30.62	13.21	2.318	–6.3	—	—	1.61
(2-Methyl 1-butanol) → *iso*-amyl alcohol										
(Methyl chloride) → dichloromethane										
Methyl ether	C_2H_6O	46.07	31.70	28.84	13.84	2.084	–24.9	—	—	1.43
Methyl ethyl ketone	C_4H_8O	72.10	33.90	31.46	12.89	2.441	79.6	434	2.30	1.43
1-Methylnaphthalene	$C_{11}H_{10}$	142.19	40.88	39.33	12.95	3.038	244.7	323	1.58	1.12
Methyl methacrylate	$C_5H_8O_2$	100.11	27.37	25.61	12.33	2.078	101.0	360	1.91	—
Methyl nitrate	CH_3NO_3	77.04	8.67	7.81	75.10	0.104	64.6	409	2.04	0.99
2-Methyl propane) → *iso*-butane										
Naphthalene[a]	$C_{10}H_8$	128.16	40.21	38.84	12.96	2.996	217.9	—	1.18	1.03
Nitrobenzene	$C_6H_5NO_2$	123.11	25.11	24.22	14.90	1.625	210.7	330	1.52	—
Nitroglycerin	$C_3H_5N_3O_9$	227.09	6.82	6.34	—	—	Unstable	462	1.49	—
Nitromethane	CH_3NO_2	61.04	11.62	10.54	15.08	0.699	101.1	567	1.74	0.94
n-Nonane	C_9H_{20}	128.25	47.76	44.33	12.69	3.493	150.6	295	2.10	1.65
Octamethyl-cyclotetrasiloxane	$C_8H_{24}Si_4O_4$	296.62	26.90	25.10	14.56	1.725	175.0	127	1.88	—
n-Octane	C_8H_{18}	114.22	47.90	44.44	12.69	3.502	125.6	301	2.20	1.65
iso-Octane	C_8H_{18}	114.22	47.77	44.31	12.65	3.502	117.7	272	2.15	1.65
1-Octene	C_8H_{10}	112.21	47.33	44.20	12.92	3.422	121.3	301	2.19	1.59

Table C.2 ***(Continued)***

Material	Composition	Molecular Weight, W	Gross, Δh_c^u (MJ/kg)	Net, Δh_c^l (MJ/kg)	$\Delta h_c^l/r_o$ (MJ/kg O_2)	Oxygen Fuel Mass Ratio, r_o	Boiling Temp., T_b (°C)	Latent Heat of Vaporization Δh_v (kJ/kg)	Liquid Heat Capacity, C_{pl} (kJ/kg·°C)	Vapor Heat Capacity, C_{pv} (kJ/kg·°C)
(1-Octylene) → 1-octene										
1,2-Pentadiene	C_5H_8	68.11	47.31	44.71	13.60	3.288	44.9	405	2.21	1.55
n-Pentane	C_5H_{12}	72.15	48.64	44.98	12.68	3.548	36.0	357	2.33	1.67
1-Pentene	C_5H_{10}	70.13	47.77	44.64	13.04	3.422	30.0	359	2.16	1.56
Phenol[a]	C_6H_6O	94.11	32.45	31.05	13.05	2.380	181.8	433	1.43	1.10
Phosgene	$COCl_2$	98.92	1.74	1.74	10.74	0.162	8.3	247	1.02	0.58
Propadiene	C_3H_4	40.06	48.54	46.35	14.51	3.195	–34.6	—	—	1.44
Propane	C_3H_8	44.09	50.35	46.36	12.78	3.629	–42.2	—	2.23	1.67
n-Propanol	C_3H_8O	60.09	33.61	30.68	12.81	2.396	97.2	686	2.50	1.45
iso-Propanol	C_3H_8O	60.09	33.38	30.45	12.71	2.396	80.3	663	2.42	1.48
Propene	C_3H_6	42.08	48.92	45.79	13.38	3.422	–47.7	—	—	1.52
(*iso*-Propylbenzene) → cumene										
(Propylene) → propene										
iso-Propyl ether	$C_6H_{14}O$	102.17	39.26	36.25	12.86	2.819	67.8	286	2.14	1.55
Propyne	C_3H_4	40.06	48.36	46.17	14.45	3.195	–23.3	—	—	1.51
Styrene	C_8H_8	104.14	42.21	40.52	13.19	3.073	145.2	356	1.76	1.17
Sucrose[a]	$C_{12}H_{22}O_{11}$	342.30	16.49	15.08	13.44	1.122	—	—	1.24	—
1,2,3,4-Tetrahydronaphthalene) → tetralin										
Tetralin	$C_{10}H_{12}$	132.20	42.60	40.60	12.90	3.147	207.0	425	1.64	1.19
Tetranitromethane	CN_4O_8	196.04	2.20	2.20	—	—	125.7	196	—	—
Toluene	C_7H_8	92.13	42.43	40.52	12.97	3.126	110.4	360	1.67	1.12
Toluene diisocyanate	$C_9H_6N_2O_2$	174.16	24.32	23.56	13.50	1.746	120.0	—	1.65	—
Triethanolamine	$C_6H_{15}NO_3$	149.19	29.29	27.08	15.30	1.770	360.0	—	—	—
Triethylamine	$C_6H_{15}N$	101.19	43.19	39.93	12.95	3.083	89.5	303	2.22	1.59
1,1,2-Trichloroethane	$C_2H_3Cl_3$	133.42	7.77	7.28	11.02	0.660	114.0	260	1.11	0.67
Trichloroethylene	C_2HCl_3	131.40	6.77	6.60	12.05	0.548	86.9	245	1.07	0.61
Trichloromethane	$CHCl_3$	119.39	3.39	3.21	9.60	0.335	61.7	249	0.97	0.55
Trinitromethane	CHN_3O_6	151.04	3.41	3.25	—	—	Unstable	—	—	—
Trinitrotoluene[a]	$C_7H_5N_3O_6$	227.13	15.12	14.64	19.80	0.740	240.0	322	1.40	—
Trioxane	$C_3H_6O_3$	90.08	16.57	15.11	14.17	1.066	114.5	450	—	—
Urea[a]	CH_4ON_2	60.06	10.52	9.06	11.34	0.799	—	—	—	1.55
Vinyl acetate	$C_4H_6O_2$	86.09	24.18	22.65	13.54	1.673	72.5	167	2.00	1.05
Vinyl acetylene	C_4H_4	52.07	47.05	45.36	14.76	3.073	5.1	—	—	1.41
Vinyl bromide	C_2H_3Br	106.96	12.10	11.48	13.95	0.823	15.6	—	2.42	0.53
Vinyl chloride	C_2H_3Cl	62.50	20.02	16.86	11.97	1.408	–13.8	—	—	0.86
(Vinyl trichloride) → 1,1,2-trichlorolthane										
Xylenes	C_8H_{10}	106.16	42.89	40.82	12.90	3.165	138–144	343	1.72	1.21
Xylidene	$C_8H_{11}N$	121.22	38.28	36.29	12.79	2.838	192.7	366	1.77	—

[a]Denotes substance in crystalline solid form; otherwise, liquid if $T_b > 25$°C, gaseous if $T_b > 25$°C.

Table C.3 *Heats of Combustion and Related Properties of Plastics*[7]

Material	Unit Composition	Molecular Weight, W	Gross, Δh_c^u (MJ/kg)	Net, Δh_c^l (MJ/kg)	$\Delta h_c^l/r_o$ (MJ/kg O_2)	Oxygen Fuel Mass Ratio, r_o	Heat Capacity Solid, C_{ps} (kJ/kg·°C)
Acrylonitrile-butadiene styrene copolymer	—	—	35.25	33.75			1.41–1.59
Bisphenol A epoxy	$C_{11.85}H_{20.37}O_{2.83}N_{0.3}$	212.10	33.53	31.42	13.41	2.343	
Butadiene-acrylonitrile 37% copolymer	—	—	39.94				
Butadiene/styrene 8.58% copolymer	$C_{4.18}H_{6.09}$	56.30	44.84	42.49	13.11	3.241	1.94
Butadiene/styrene 25.5% copolymer	$C_{4.60}H_{6.29}$	61.55	44.19	41.95	13.07	3.209	1.82
Cellulose acetate (triacetate)	$C_{12}H_{16}O_8$	288.14	18.88	17.66	13.25	1.333	1.34
Cellulose acetate-butyrate	$C_{12}H_{18}O_7$	274.27	23.70	22.3	14.67	1.517	1.70
Epoxy, unhardened	$C_{31}H_{36}O_{5.5}$	496.63	32.92	31.32	13.05	2.400	
Epoxy, hardened	$C_{39}H_{40}O_{8.5}$	644.74	30.27	28.90	13.01	2.221	
Melamine formaldehyde (Formica™)	$C_6H_6N_6$	162.08	19.33	18.52	12.51	1.481	1.46
Nylon 6	$C_6H_{11}NO$	113.08	30.1–31.7	28.0–29.6	12.30	2.335	1.52
Nylon 6,6	$C_{12}H_{22}N_2O_2$	226.16	31.6–31.7	29.5–29.6	12.30	2.405	1.70
Nylon 11 (Rilsan)	$C_{11}H_{21}NO$	183.14	36.99	34.47	12.33	2.796	1.70–2.30
Phenol formaldehyde	$C_{15}H_{12}O_2$	224.17	27.9–31.6	26.7–30.4	11.80	2.427	1.70
foam			21.6–27.4	20.2–26.2			
Polyacenaphthalene	$C_{12}H_8$	152.14	39.23	38.14	12.95	2.945	
Polyacrylonitrile	C_3H_3N	53.04	32.22	30.98	13.70	2.262	1.50
Polyallylphthalate	$C_{14}H_{14}O$	198.17	27.74	26.19	9.54	2.745	
(Polyamides) → nylon							
Poly-1,4-butadiene	C_4H_6	54.05	45.19	42.75	13.13	3.256	
Poly-1-butene	C_4H_8	56.05	46.48	43.35	12.65	3.426	1.88
Polycarbonate	$C_{16}H_{14}O_3$	254.19	30.99	29.78	13.14	2.266	1.26
Polycarbon suboxide	C_3O_2	68.03	13.78	13.78	14.64	0.941	
Polychlorotrifluorethylene	C_2F_3Cl	116.47	1.12	1.12	2.04	0.549	0.92
Polydiphenylbutadiene	$C_{16}H_{10}$	202.18	39.30	38.2	13.05	2.928	
Polyester, unsaturated	$C_{5.77}H_{6.25}O_{1.63}$	101.60	21.6–29.8	20.3–28.5	11.90	2.053	1.20–2.30
Polyether, chlorinated	$C_5H_8OCl_2$	154.97	17.84	16.71	12.45	1.342	
Polyethylene	C_2H_4	28.03	46.2–46.5	43.1–43.4	12.63	3.425	1.83–2.30
Polyethylene oxide	C_2H_4O	44.02	26.65	24.66	13.57	1.817	
Polyethylene terephthalate	$C_{10}H_8O_4$	192.11	22.18	21.27	12.77	1.666	1.00
Polyformaldehyde	CH_2O	30.01	16.93	15.86	14.88	1.066	1.46
Poly-1-hexene sulfone	$C_6H_{12}SO_2$	148.13	29.78	28.00	14.40	1.944	
Polyhydrocyanic acid	HCN	27.02	23.26	22.45	15.17	1.480	
(Polyisobutylene) → poly-1-butene							
Polyisocyanurate foam	—		26.3	22.2–26.2			
Polyisoprene	C_5H_8	68.06	44.90	42.30	12.90	3.291	
Poly-3-methyl-1-butene	C_5H_{10}	70.06	46.55	43.42	12.67	3.426	
Polymethyl methacrylate	$C_5H_8O_2$	100.06	26.64	24.88	12.97	1.919	1.44
Poly-4-methyl-1-pentene	C_6H_{12}	84.08	46.52	43.39	12.67	3.425	2.18
Poly-α-methylstyrene	C_9H_{10}	118.11	42.31	40.45	13.00	3.116	
Polynitroethylene	$C_2H_3O_2N$	73.03	15.96	15.06	19.64	0.767	
Polyoxymethylene	CH_2O	30.01	16.93	15.65	14.68	1.066	
Polyoxytrimethylene	C_3H_6O	58.04	31.52	29.25	13.27	2.205	
Poly-1-pentene	C_5H_{10}	70.06	45.58	42.45	12.39	3.426	
Polyphenylacetylene	C_8H_6	102.09	40.00	38.70	13.00	2.978	
Polyphenylene oxide	C_8H_8O	120.09	34.59	33.13	13.09	2.531	1.34
Polypropene sulfone	$C_3H_6SO_2$	106.10	23.82	22.58	16.64	1.357	
Poly-β-propiolactone	$C_3H_4O_2$	72.14	19.35	18.13	13.62	1.331	
Polypropylene	C_3H_6	42.04	46.37	43.23	12.62	3.824	2.10

Table C.3 (Continued)

Material	Unit Composition	Molecular Weight, W	Gross, Δh_c^u (MJ/kg)	Net, Δh_c^l (MJ/kg)	$\Delta h_c^l/r_o$ (MJ/kg O_2)	Oxygen Fuel Mass Ratio, r_o	Heat Capacity Solid, C_{ps} (kJ/kg·°C)
Polypropylene oxide	C_3H_6O	58.04	31.17	28.90	13.11	2.205	
Polystyrene	C_8H_8	104.10	41.4–42.5	39.7–39.8	12.93	3.074	1.40
Polystyrene-foam	—		39.7	35.6–40.8			
Polystyrene-foam, FR	—		41.2–42.9				
Polysulfones, butene	$C_4H_8SO_2$	120.11	24.04–26.47	22.25–25.01	14.79	1.598	1.30
Polysulfur	S	32.06	9.72	9.72	9.74	0.998	
Polytetrafluoroethylene	C_2F_4	100.02	5.00	5.00	7.81	0.640	1.02
Polytetrahydrofuran	C_4H_8O	72.05	34.39	31.85	13.04	2.443	
Polyurea	$C_{15}H_{18}O_4N_4$	318.20	24.91	23.67	13.45	1.760	
Polyurethane	$C_{6.3}H_{7.1}NO_{2.1}$	130.30	23.90	22.70	13.16	1.725	1.75–1.84
Polyurethane-foam	—		26.1–31.6	23.2–28.0			
Polyurethane-foam, FR	—		24.0–25.0				
Polyvinyl acetate	$C_4H_6O_2$	86.05	23.04	21.51	12.86	1.673	
Polyvinyl alcohol	C_2H_4	44.03	25.00	23.01	12.66	1.817	1.70
Polyvinyl butyral	$C_8H_{14}O_2$	142.10	32.90	30.70	13.00	2.365	
Polyvinyl chloride	C_2H_3Cl	62.48	17.95	16.90	12.00	1.408	0.90–1.20
Polyvinyl-foam	—		22.83				1.30–2.10
Polyvinyl fluoride	C_2H_3F	46.02	21.70	20.27	10.60	1.912	
Polyvinylidene chloride	$C_2H_2Cl_2$	96.93	10.52	10.07	12.21	0.825	1.34
Polyvinylidene fluoride	$C_2H_2F_2$	64.02	14.77	14.08	11.26	1.250	1.38
Urea formaldehyde	$C_3H_6O_2N_2$	102.05	15.90	14.61	13.31	1.098	1.60–2.10
Urea formaldehyde-foam	—	—	14.80				

Table C.4 *Heats of Combustion of Miscellaneous Materials*[7]

Material	Gross, Δh_c^u (MJ/kg)	Net, Δh_c^l (MJ/kg)
Acetate (see cellulose acetate)		
Acrylic fiber	30.6–30.8	
Blasting powder	2.1–2.4	
Butter	38.5	
Celluloid (cellulose nitrate and camphor)	17.5–20.6	16.4–19.2
Cellulose acetate fiber, $C_8H_{12}O_6$	17.8–18.4	16.4–17.0
Cellulose diacetate fiber, $C_{10}H_{14}O_7$	18.7	
Cellulose nitrate, $C_6H_9N_1O_7/C_6H_8N_2O_9/C_6H_7N_3O_{11}$	9.11–13.48	
Cellulose triacetate fiber, $C_{12}H_{16}O_8$	18.8	17.6
Charcoal	33.7–34.7	33.2–34.2
Coal—anthracite	30.9–34.6	30.5–34.2
—bituminous	24.7–36.3	23.6–35.2
Coke	28.0–31.0	28.0–31.0
Cork	26.1	
Cotton	16.5–20.4	
Dynamite	5.4	
Epoxy, $C_{11.9}H_{20.4}O_{2.8}N_{0.3}/C_{6.064}H_{7.550}O_{1.222}$	32.8–33.5	31.1–31.4
Fat, animal	39.8	
Flint powder	3.0–3.1	
Fuel oil—No. 1	46.1	
—No. 6	42.5	
Gasketing—chlorosulfonated polyethylene (Hypalon)	28.5	
—vinylidene fluoride/ hexafluoropropylene (Fluorel, Viton A)	14.0–15.1	

Table C.4 ***(Continued)***

Material	Gross, Δh_c^u (MJ/kg)	Net, Δh_c^l (MJ/kg)
Gasoline	46.8	43.7
Jet fuel—JP1		43.0
—JP3		43.5
—JP4	46.6	43.5
—JP5	45.9	43.0
Kerosene (jet fuel A)	46.4	43.3
Lanolin (wool fat)	40.8	
Lard	40.1	
Leather	18.2–19.8	
Lignin, $C_{2.6}H_3O$	24.7–26.4	23.4–25.1
Lignite	22.4–33.3	
Modacrylic fiber	24.7	
Naphtha	43.0–47.1	40.9–43.9
Neoprene, C_5H_5Cl—gum	24.3	
—foam	9.7–26.8	
Nomex™ (polymethaphenylene isophthalamide) fiber, $C_{14}H_{10}O_2N_2$	27.0–28.7	
Oil—castor	37.1	
—linseed	39.2–39.4	
—mineral	45.8–46.0	
—olive	39.6	
—solar	41.8	
Paper—brown	16.3–17.9	
—magazine	12.7	
—newsprint	19.7	
—wax	21.5	
Paraffin wax	46.2	43.1
Peat	16.7–21.6	
Petroleum jelly ($C_{7.118}H_{12.957}O_{0.091}$)	45.9	
Rayon fiber	13.6–19.5	
Rubber—buna N	34.7–35.6	
—butyl	45.8	
—isoprene (natural) C_5H_8	44.9	42.3
—latex foam	33.9–40.6	
—GRS	44.2	
—tire, auto	32.6	
Silicone rubber (SiC_2H_6O)	15.5–16.8	
—foam	14.0–19.5	
Sisal	15.9	
Spandex fiber	31.4	
Starch	17.6	16.2
Straw	15.6	
Sulfur—rhombic		9.28
—monoclinic		9.29
Tobacco	15.8	
Wheat	15.0	
Wood—beech	20.0	18.7
—birch	20.0	18.7
—douglas fir	21.0	19.6
—maple	19.1	17.8
—red oak	20.2	18.7
—spruce	21.8	20.4
—white pine	19.2	17.8
—hardboard	19.9	
Woodflour	19.8	
Wool	20.7–26.6	

APPENDIX D

Configuration Factors

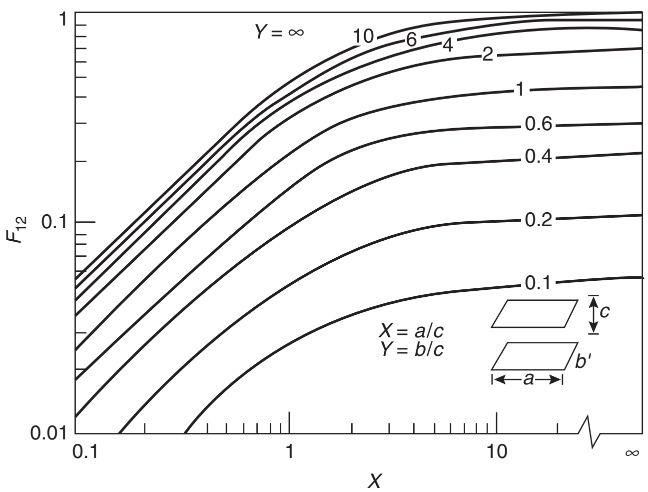
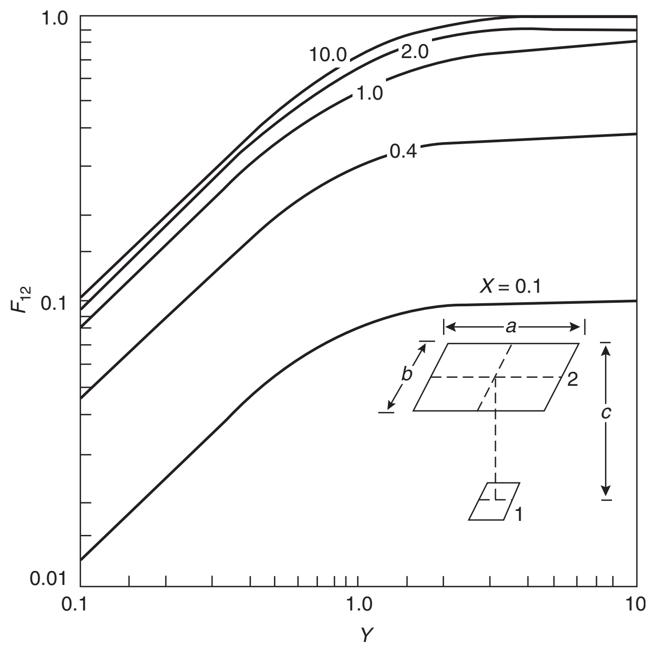


Figure D-1. ***View factor for parallel, rectangular plates.[8]***



$$F_{12} = \frac{2}{\pi}\left[\frac{X}{\sqrt{1+X^2}}\tan^{-1}\frac{Y}{\sqrt{1+X^2}} + \frac{Y}{\sqrt{1+Y^2}}\tan^{-1}\frac{X}{\sqrt{1+Y^2}}\right]$$

$$X = \frac{A}{C}$$

$$Y = \frac{B}{C}$$

Figure D-2. ***View factor for parallel, rectangular radiator.[8]***

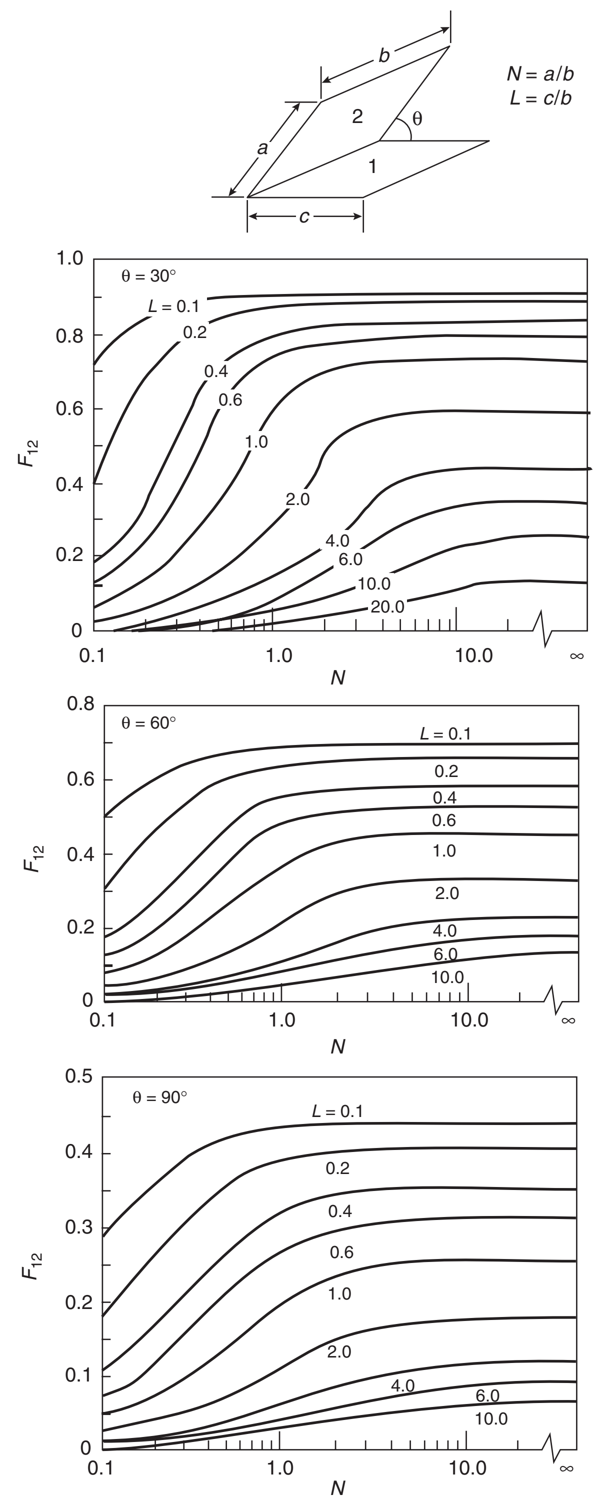
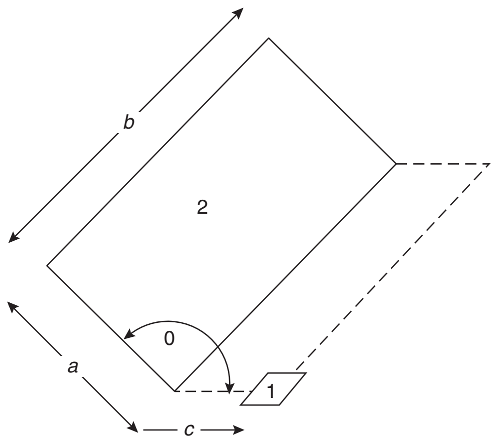


Figure D-3. ***View factor for rectangular plates at various angles.[8]***



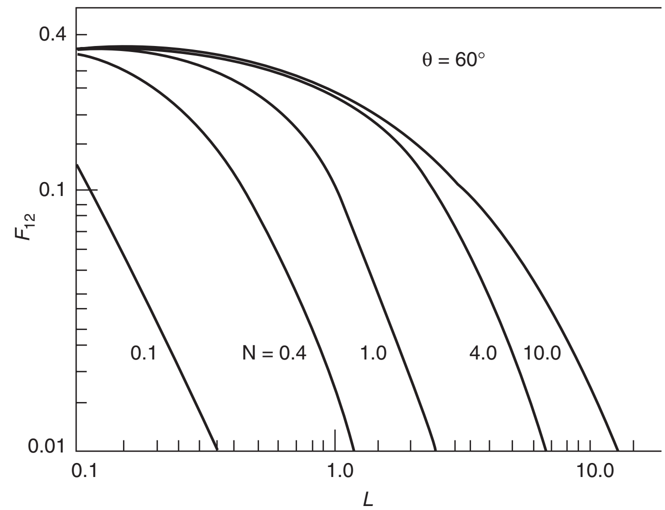
$$F_{12} = \frac{1}{2\pi}\left\{ \tan^{-1}\left(\frac{1}{L}\right) + V\,(N\cos\phi - \phi\, L)\tan^{-1} V + \frac{\cos\phi}{W}\left[\tan^{-1}\left(\frac{N - L\cos\phi}{W}\right) + \tan^{-1}\left(\frac{L\cos\phi}{W}\right)\right]\right\}$$

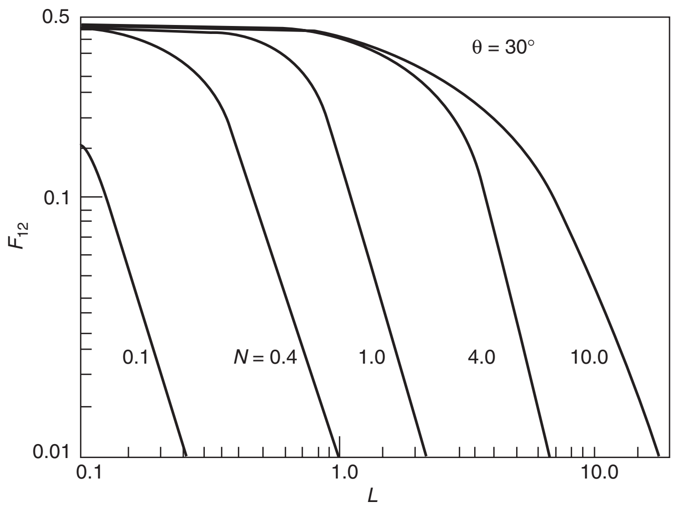
$$V = \frac{1}{\sqrt{N^2 + L^2 - 2NL\cos\phi}}$$

$$W = \sqrt{1 + L^2 \sin^2\phi}$$

$$N = \frac{a}{b}$$

$$L = \frac{c}{b}$$





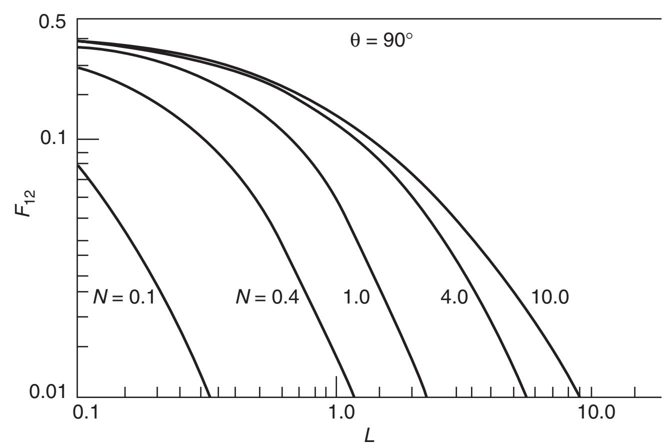
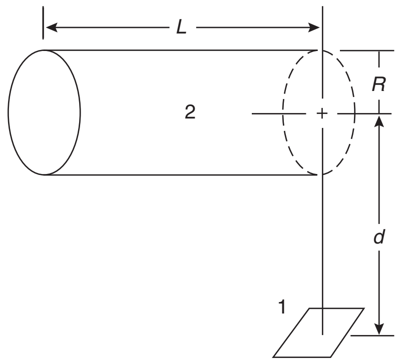


Figure D-4. ***View factor for rectangular radiator to differential area at various angles.[8]***



$$F_{12} = \frac{1}{\pi D} \tan^{-1}\left(\frac{L}{\sqrt{D^2-1}}\right) + \frac{L}{\pi}\left[\frac{A-2D}{D\sqrt{AB}} \tan^{-1}\sqrt{\frac{A(D-1)}{B(D+1)}} - \frac{1}{D}\tan^{-1}\sqrt{\frac{D-1}{D+1}}\right]$$

$$D = \frac{d}{r} \qquad L = \frac{L}{R}$$

$$A = (D+1)^2 + L^2 \qquad B = (D-1)^2 + L^2$$

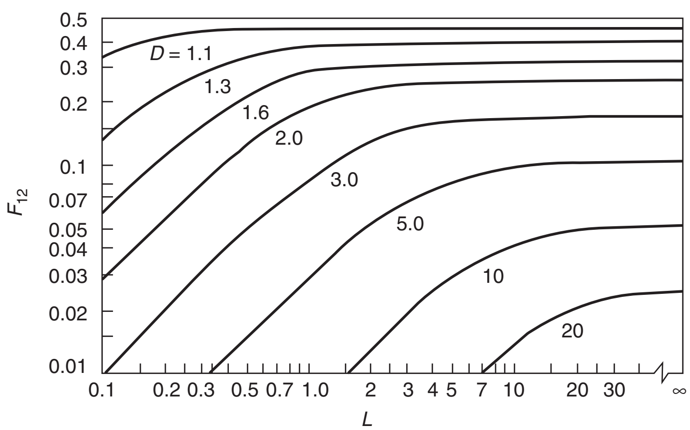
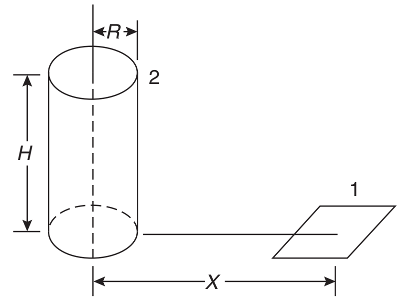


Figure D-5. ***Cylindrical radiator to parallel receiver.[8]***



$$F_{12} = \frac{1}{\pi}\left[\tan^{-1}\sqrt{\frac{X'+R'}{X'-R'}} - \frac{(1.0+X'^2-R'^2)}{(1.0+X'^2+R'^2)}\tan^{-1}\sqrt{\frac{X'+R'}{X'-R'}}\right]$$

$$X' = \frac{X}{H}$$

$$R' = \frac{R}{H}$$

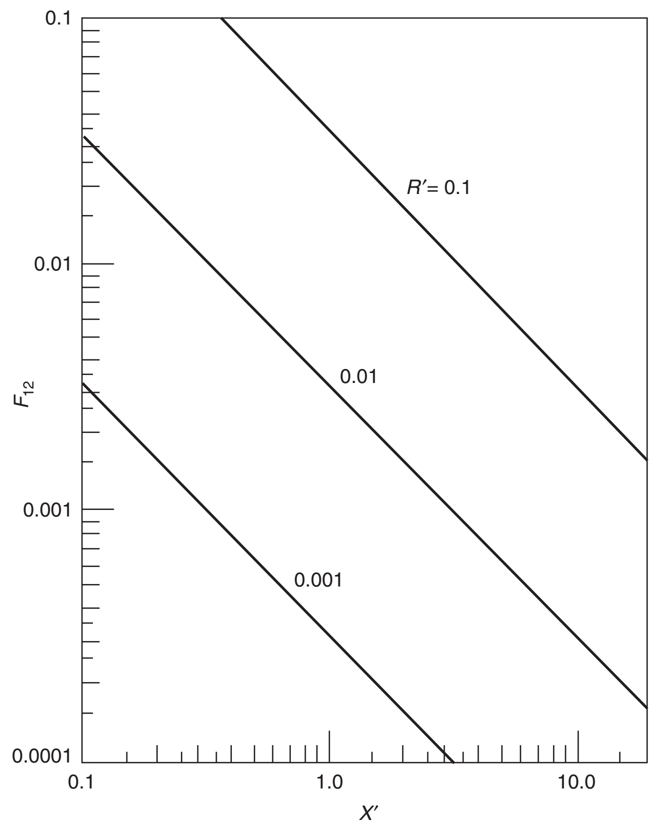
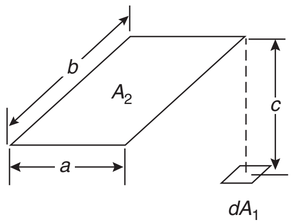


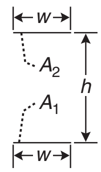
Figure D-6. ***View factor for cylindrical radiator to normal target.[8]***



Plane element dA_1 to plane parallel rectangle; normal to element passes through corner of rectangle.

$X = \dfrac{a}{c} \qquad Y = \dfrac{b}{c}$

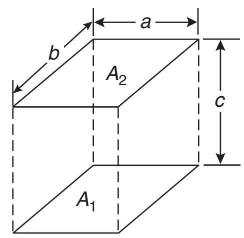
$$F_{d1-2} = \frac{1}{2\pi}\left(\frac{X}{\sqrt{1+X^2}}\tan^{-1}\frac{Y}{\sqrt{1+X^2}} + \frac{X}{\sqrt{1+Y^2}}\tan^{-1}\frac{X}{\sqrt{1+Y^2}}\right)$$



Two infinitely long, directly opposed parallel plates of the same finite width

$H = \dfrac{h}{w}$

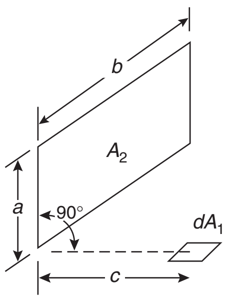
$F_{1-2} = F_{2-1} = \sqrt{1+H^2} - H$



Identical, parallel, directly opposed rectangles.

$Y = \dfrac{a}{c} \qquad Y = \dfrac{b}{c}$

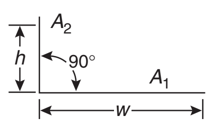
$$F_{1-2} = \frac{2}{\pi XY}\left\{ \ln\left[\frac{(1+X^2)(1+Y^2)}{1+X^2+Y^2}\right]^{1/2} + X\sqrt{1+Y^2}\,\tan^{-1}\frac{X}{\sqrt{1+Y^2}} + Y\sqrt{1+X^2}\,\tan^{-1}\frac{Y}{\sqrt{1+X^2}} - X\tan^{-1}X - Y\tan^{-1}Y \right\}$$



Plane element dA_1 to rectangle in plane 90° to plane of element

$X = \dfrac{a}{b} \qquad Y = \dfrac{c}{b}$

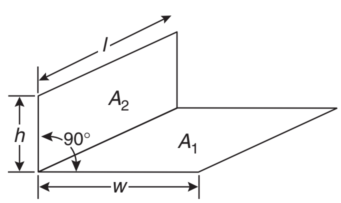
$$F_{d1-2} = \frac{1}{2\pi}\left(\tan^{-1}\frac{1}{Y} - \frac{Y}{\sqrt{X^2+Y^2}}\tan^{-1}\frac{1}{\sqrt{X^2+Y^2}}\right)$$



Two infinitely long plates of unequal widths h and w, having one common edge and having an angle of 90° to each other

$H = \dfrac{h}{w}$

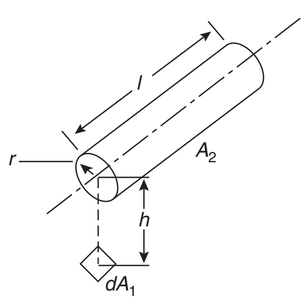
$F_{1-2} = \dfrac{1}{2}\left(1 + H - \sqrt{1+H^2}\right)$



Two finite rectangles of same length, having one common edge and having an angle of 90° to each other

$H = \dfrac{h}{l} \qquad H = \dfrac{w}{l}$

$$F_{1-2} = \frac{1}{\pi W}\left(W\tan^{-1}\frac{1}{W} + H\tan^{-1}\frac{1}{H} - \sqrt{H^2+W^2}\,\tan^{-1}\frac{1}{\sqrt{H^2+W^2}} + \frac{1}{4}\ln\left\{\frac{(1+W^2)(1+H^2)}{1-W^2+H^2}\left[\frac{W^2(1+W^2+H^2)}{(1+W^2)(W^2+H^2)}\right]^{W^2}\left[\frac{H^2(1+H^2+W^2)}{(1+H^2)(H^2+W^2)}\right]^{H^2}\right\}\right)$$



Plane element dA_1 to right circular cylinder of finite length l and radius r; normal to element passes through one end of cylinder and is perpendicular to cylinder axis

$L = \dfrac{l}{r} \qquad H = \dfrac{h}{r}$

$X = (1+H)^2 + L^2$
$Y = (1-H)^2 + L^2$

$$F_{d1-2} = \frac{1}{\pi H}\tan^{-1}\frac{1}{\sqrt{H^2-1}} + \frac{L}{\pi}\left[\frac{X-2H}{H\sqrt{XY}}\tan^{-1}\sqrt{\frac{X(H-1)}{Y(H+1)}} - \frac{1}{H}\tan^{-1}\sqrt{\frac{(H-1)}{(H+1)}}\right]$$

Figure D-7. ***View factor equations for various geometries.***[9]

APPENDIX E

Piping Properties

Table E.1 ***Properties of Steel Pipe[10]***

Nominal Pipe Size (in.)	Outside Diam. (in.)	Schedule No.	Wall Thickness (in.)	Inside Diam. (in.)	Cross-Sectional Area		Circumference (ft) or Surface (sq ft/ft of length)		Capacity at Velocity (1 ft/s)		Weight of Plain-End Pipe (lb/ft)
					Metal (sq in.)	Flow (sq ft)	Outside	Inside	U.S. gal/min	Water (lb/hr)	
1/8	0.405	10S	0.049	0.307	0.055	0.00051	0.106	0.0804	0.231	115.5	0.19
		40ST, 40S	0.068	0.269	0.072	0.00040	0.106	0.0705	0.179	89.5	0.24
		80XS, 80S	0.095	0.215	0.093	0.00025	0.106	0.0563	0.113	56.5	0.31
1/4	0.540	10S	0.065	0.410	0.097	0.00092	0.141	0.107	0.412	206.5	0.33
		40ST, 40S	0.088	0.364	0.125	0.00072	0.141	0.095	0.323	161.5	0.42
		80XS, 80S	0.119	0.302	0.157	0.00050	0.141	0.079	0.224	112.0	0.54
3/8	0.675	10S	0.065	0.545	0.125	0.00162	0.177	0.143	0.727	363.5	0.42
		40ST, 40S	0.091	0.493	0.167	0.00133	0.177	0.129	0.596	298.0	0.57
		80XS, 80S	0.126	0.423	0.217	0.00098	0.177	0.111	0.440	220.0	0.74
1/2	0.840	5S	0.065	0.710	0.158	0.00275	0.220	0.186	1.234	617.0	0.54
		10S	0.083	0.674	0.197	0.00248	0.220	0.176	1.112	556.0	0.67
		40ST, 40S	0.109	0.622	0.250	0.00211	0.220	0.163	0.945	472.0	0.85
		80XS, 80S	0.147	0.546	0.320	0.00163	0.220	0.143	0.730	365.0	1.09
		160	0.188	0.464	0.385	0.00117	0.220	0.122	0.527	263.5	1.31
		XX	0.294	0.252	0.504	0.00035	0.220	0.066	0.155	77.5	1.71
3/4	1.050	5S	0.065	0.920	0.201	0.00461	0.275	0.241	2.072	1036.0	0.69
		10S	0.083	0.884	0.252	0.00426	0.275	0.231	1.903	951.5	0.86
		40ST, 40S	0.113	0.824	0.333	0.00371	0.275	0.216	1.665	832.5	1.13
		80XS, 80S	0.154	0.742	0.433	0.00300	0.275	0.194	1.345	672.5	1.47
		160	0.219	0.612	0.572	0.00204	0.275	0.160	0.917	458.5	1.94
		XX	0.308	0.434	0.718	0.00103	0.275	0.114	0.461	230.5	2.44
1	1.315	5S	0.065	1.185	0.255	0.00768	0.344	0.310	3.449	1725	0.87
		10S	0.109	1.097	0.413	0.00656	0.344	0.287	2.946	1473	1.40
		40ST, 40S	0.133	1.049	0.494	0.00600	0.344	0.275	2.690	1345	1.68
		80XS, 80S	0.179	0.957	0.639	0.00499	0.344	0.250	2.240	1120	2.17
		160	0.250	0.815	0.836	0.00362	0.344	0.213	1.625	812.5	2.84
		XX	0.358	0.599	1.076	0.00196	0.344	0.157	0.878	439.0	3.66
1 1/4	1.660	5S	0.065	1.530	0.326	0.01277	0.435	0.401	5.73	2865	1.11
		10S	0.109	1.442	0.531	0.01134	0.435	0.378	5.09	2545	1.81
		40ST, 40S	0.140	1.380	0.668	0.01040	0.435	0.361	4.57	2285	2.27
		80XS, 80S	0.191	1.278	0.881	0.00891	0.435	0.335	3.99	1995	3.00
		160	0.250	1.160	1.107	0.00734	0.435	0.304	3.29	1645	3.76
		XX	0.382	0.896	1.534	0.00438	0.435	0.235	1.97	985	5.21
1 1/2	1.900	5S	0.065	1.770	0.375	0.01709	0.497	0.463	7.67	3835	1.28
		10S	0.109	1.682	0.614	0.01543	0.497	0.440	6.94	3465	2.09
		40ST, 40S	0.145	1.610	0.800	0.01414	0.497	0.421	6.34	3170	2.72
		80XS, 80S	0.200	1.500	1.069	0.01225	0.497	0.393	5.49	2745	3.63
		160	0.281	1.338	1.429	0.00976	0.497	0.350	4.38	2190	4.86
		XX	0.400	1.100	1.885	0.00660	0.497	0.288	2.96	1480	6.41
2	2.375	5S	0.065	2.245	0.472	0.02749	0.622	0.588	12.34	6170	1.61
		10S	0.109	2.157	0.776	0.02538	0.622	0.565	11.39	5695	2.64
		40ST, 40S	0.154	2.067	1.075	0.02330	0.622	0.541	10.45	5225	3.65
		80ST, 80S	0.218	1.939	1.477	0.02050	0.622	0.508	9.20	4600	5.02
		160	0.344	1.687	2.195	0.01552	0.622	0.436	6.97	3485	7.46
		XX	0.436	1.503	2.656	0.01232	0.622	0.393	5.53	2765	9.03

Table E.1 *(Continued)*

Nominal Pipe Size (in.)	Outside Diam. (in.)	Schedule No.	Wall Thickness (in.)	Inside Diam. (in.)	Cross-Sectional Area: Metal (sq in.)	Cross-Sectional Area: Flow (sq ft)	Circumference (ft) or Surface (sq ft/ft of length): Outside	Circumference (ft) or Surface (sq ft/ft of length): Inside	Capacity at Velocity (1 ft/s): U.S. gal/min	Capacity at Velocity (1 ft/s): Water (lb/hr)	Weight of Plain-End Pipe (lb/ft)
$2^1/_2$	2.875	5S	0.083	2.709	0.728	0.04003	0.753	0.709	17.97	8985	2.48
		10S	0.120	2.635	1.039	0.03787	0.753	0.690	17.00	8500	3.53
		40ST, 40S	0.203	2.469	1.704	0.03322	0.753	0.647	14.92	7460	5.79
		80XS, 80S	0.276	2.323	2.254	0.02942	0.753	0.608	13.20	6600	7.66
		160	0.375	2.125	2.945	0.02463	0.753	0.556	11.07	5535	10.01
		XX	0.552	1.771	4.028	0.01711	0.753	0.464	7.68	3840	13.70
3	3.500	5S	0.083	3.334	0.891	0.06063	0.916	0.873	27.21	13,605	3.03
		10S	0.120	3.260	1.274	0.05796	0.916	0.853	26.02	13,010	4.33
		40ST, 40S	0.216	3.068	2.228	0.05130	0.916	0.803	23.00	11,500	7.58
		80XS, 80S	0.300	2.900	3.016	0.04587	0.916	0.759	20.55	10,275	10.25
		160	0.438	2.624	4.213	0.03755	0.916	0.687	16.86	8430	14.31
		XX	0.600	2.300	5.466	0.02885	0.916	0.602	12.95	6475	18.58
$3^1/_2$	4.0	5S	0.083	3.834	1.021	0.08017	1.047	1.004	35.98	17,990	3.48
		10S	0.120	3.760	1.463	0.07711	1.047	0.984	34.61	17,305	4.97
		40ST, 40S	0.226	3.548	2.680	0.06870	1.047	0.929	30.80	15,400	9.11
		80XS, 80S	0.318	3.364	3.678	0.06170	1.047	0.881	27.70	13,850	12.51
4	4.5	5S	0.083	4.334	1.152	0.10245	1.178	1.135	46.0	23,000	3.92
		10S	0.120	4.260	1.651	0.09898	1.178	1.115	44.4	22,200	5.61
		40ST, 40S	0.237	4.026	3.17	0.08840	1.178	1.054	39.6	19,800	10.79
		80XS, 80S	0.337	3.826	4.41	0.07986	1.178	1.002	35.8	17,900	14.98
		120	0.438	3.624	5.58	0.07170	1.178	0.949	32.2	16,100	18.98
		160	0.531	3.438	6.62	0.06647	1.178	0.900	28.9	14,450	22.52
		XX	0.674	3.152	8.10	0.05419	1.178	0.825	24.3	12,150	27.54
5	5.563	5S	0.109	5.345	1.87	0.1558	1.456	1.399	69.9	34,950	6.36
		10S	0.134	5.295	2.29	0.1529	1.456	1.386	68.6	34,300	7.77
		40ST, 40S	0.258	5.047	4.30	0.1390	1.456	1.321	62.3	31,150	14.62
		80XS, 80S	0.375	4.813	6.11	0.1263	1.456	1.260	57.7	28,850	20.78
		120	0.500	4.563	7.95	0.1136	1.456	1.195	51.0	25,500	27.04
		160	0.625	4.313	9.70	0.1015	1.456	1.129	45.5	22,750	32.96
		XX	0.750	4.063	11.34	0.0900	1.456	1.064	40.4	20,200	38.55
6	6.625	5S	0.109	6.407	2.23	0.2239	1.734	1.677	100.5	50,250	7.60
		10S	0.134	6.357	2.73	0.2204	1.734	1.664	98.9	49,450	9.29
		40ST, 40S	0.280	6.065	5.58	0.2006	1.734	1.588	90.0	45,000	18.97
		80XS, 80S	0.432	5.761	8.40	0.1810	1.734	1.508	81.1	40,550	28.57
		120	0.562	5.501	10.70	0.1650	1.734	1.440	73.9	36,950	36.42
		160	0.719	5.187	13.34	0.1467	1.734	1.358	65.9	32,950	45.34
		XX	0.864	4.897	15.64	0.1308	1.734	1.282	58.7	29,350	53.16
8	8.625	5S	0.109	8.407	2.915	0.3855	2.258	2.201	173.0	86,500	9.93
		10S	0.148	8.329	3.941	0.3784	2.258	2.180	169.8	84,900	13.40
		20	0.250	8.125	6.578	0.3601	2.258	2.127	161.5	80,750	22.36
		30	0.277	8.071	7.265	0.3553	2.258	2.113	159.4	79,700	24.70
		40ST, 40S	0.322	7.981	8.399	0.3474	2.258	2.089	155.7	77,850	28.55
		60	0.406	7.813	10.48	0.3329	2.258	2.045	149.4	74,700	35.66
		80XS, 80S	0.500	7.625	12.76	0.3171	2.258	1.996	142.3	71,150	43.39
		100	0.594	7.437	14.99	0.3017	2.258	1.947	135.4	67,700	50.93
		120	0.719	7.187	17.86	0.2817	2.258	1.882	126.4	63,200	60.69
		140	0.812	7.001	19.93	0.2673	2.258	1.833	120.0	60,000	67.79
		XX	0.875	6.875	21.30	0.2578	2.258	1.800	115.7	57,850	72.42
		160	0.906	6.813	21.97	0.2532	2.258	1.784	113.5	56,750	74.71

Table E.1 *(Continued)*

Nominal Pipe Size (in.)	Outside Diam. (in.)	Schedule No.	Wall Thickness (in.)	Inside Diam. (in.)	Cross-Sectional Area		Circumference (ft) or Surface (sq ft/ft of length)		Capacity at Velocity (1 ft/s)		Weight of Plain-End Pipe (lb/ft)
					Metal (sq in.)	Flow (sq ft)	Outside	Inside	U.S. gal/min	Water (lb/hr)	
10	10.75	5S	0.134	10.842	4.47	0.5993	2.814	2.744	269.0	134,500	15.19
		10S	0.165	10.420	5.49	0.5922	2.814	2.728	265.8	132,900	18.65
		20	0.250	10.250	8.25	0.5731	2.814	2.685	257.0	128,500	28.04
		30	0.307	10.136	10.07	0.5603	2.814	2.655	252.0	126,000	34.24
		40ST, 40S	0.365	10.020	11.91	0.5475	2.814	2.620	246.0	123,000	40.48
		80S, 60XS	0.500	9.750	16.10	0.5185	2.814	2.550	233.0	116,500	54.74
		80	0.594	9.562	18.95	0.4987	2.814	2.503	233.4	111,700	64.40
		100	0.719	9.312	22.66	0.4729	2.814	2.438	212.3	106,150	77.00
		120	0.844	9.062	26.27	0.4479	2.814	2.372	201.0	100,500	89.27
		140, XX	1.000	8.750	30.63	0.4176	2.814	2.291	188.0	94,000	104.13
		160	1.125	8.500	34.02	0.3941	2.814	2.225	177.0	88,500	115.65
12	12.75	5S	0.156	12.438	6.17	0.8438	3.338	3.26	378.7	189,350	20.98
		10S	0.180	12.390	7.11	0.8373	3.338	3.24	275.8	187,900	24.17
		20	0.250	12.250	9.82	0.8185	3.338	3.21	367.0	183,500	33.38
		30	0.330	12.090	12.88	0.7972	3.338	3.17	358.0	179,000	43.77
		ST, 40S	0.375	12.000	14.58	0.7854	3.338	3.14	352.5	176,250	49.56
		40	0.406	11.938	15.74	0.7773	3.338	3.13	349.0	174,500	54.56
		XS, 80S	0.500	11.750	19.24	0.7530	3.338	3.08	338.0	169,000	65.42
		60	0.562	11.626	21.52	0.7372	3.338	3.04	331.0	165,500	73.72
		80	0.688	11.374	26.07	0.7056	3.338	2.98	316.7	158,350	88.57
		100	0.844	11.062	31.57	0.6674	3.338	2.90	299.6	149,800	107.29
		120, XX	1.000	10.750	36.91	0.6303	3.338	2.81	283.0	141,500	125.49
		140	1.125	10.500	41.09	0.6013	3.338	2.75	270.0	135,000	139.68
		160	1.312	10.126	47.14	0.5592	3.338	2.65	251.0	125,500	160.33
14	14	5S	0.156	13.688	6.78	1.0219	3.665	3.58	459	229,500	23.07
		10S	0.188	13.624	8.16	1.0125	3.665	3.57	454	227,000	27.73
		10	0.250	13.500	10.80	0.9940	3.665	3.53	446	223,000	36.71
		20	0.312	13.376	13.42	0.9750	3.665	3.50	438	219,000	45.68
		30, ST	0.375	13.250	16.05	0.9575	3.665	3.47	430	215,000	54.57
		40	0.438	13.124	18.66	0.9397	3.665	3.44	422	211,000	63.37
		XS	0.500	13.000	21.21	0.9218	3.665	3.40	414	207,000	72.09
		60	0.594	12.812	25.02	0.8957	3.665	3.35	402	201,000	85.01
		80	0.750	12.500	31.22	0.8522	3.665	3.27	382	191,000	106.13
		100	0.938	12.124	38.49	0.8017	3.665	3.17	360	180,000	130.79
		120	1.094	11.812	44.36	0.7610	3.665	3.09	342	171,000	150.76
		140	1.250	11.500	50.07	0.7213	3.665	3.01	324	162,000	170.22
		160	1.406	11.188	55.63	0.6827	3.665	2.93	306	153,000	189.15
16	16	5S	0.165	15.670	8.21	1.3393	4.189	4.10	601	300,500	27.90
		10S	0.188	15.624	9.34	1.3314	4.189	4.09	598	299,000	31.75
		10	0.250	15.500	12.37	1.3104	4.189	4.06	587	293,500	42.05
		20	0.312	15.376	15.38	1.2985	4.189	4.03	578	289,000	52.36
		30, ST	0.375	15.250	18.41	1.2680	4.189	3.99	568	284,000	62.58
		40, XS	0.500	15.000	24.35	1.2272	4.189	3.93	550	275,000	82.77
		60	0.656	14.688	31.62	1.1766	4.189	3.85	528	264,000	107.54
		80	0.844	14.312	40.19	1.1171	4.189	3.75	501	250,500	136.58
		100	1.031	13.938	48.48	1.0596	4.189	3.65	474	237,000	164.86
		120	1.219	13.562	56.61	1.0032	4.189	3.55	450	225,000	192.40
		140	1.438	13.124	65.79	0.9394	4.189	3.44	422	211,000	223.57
		160	1.594	12.812	72.14	0.8953	4.189	3.35	402	201,000	245.22

Table E.1 *(Continued)*

Nominal Pipe Size (in.)	Outside Diam. (in.)	Schedule No.	Wall Thickness (in.)	Inside Diam. (in.)	Cross-Sectional Area: Metal (sq in.)	Cross-Sectional Area: Flow (sq ft)	Circumference (ft) or Surface (sq ft/ft of length): Outside	Circumference (ft) or Surface (sq ft/ft of length): Inside	Capacity at Velocity (1 ft/s): U.S. gal/min	Capacity at Velocity (1 ft/s): Water (lb/hr)	Weight of Plain-End Pipe (lb/ft)
18	18	5S	0.165	17.670	9.25	1.7029	4.712	4.63	764	382,000	31.43
		10S	0.188	17.624	10.52	1.6941	4.712	4.61	760	379,400	35.76
		10	0.250	17.500	13.94	1.6703	4.712	4.58	750	375,000	47.39
		20	0.312	17.376	17.34	1.6468	4.712	4.55	739	369,500	59.03
		ST	0.375	17.250	20.76	1.6230	4.712	4.52	728	364,000	70.59
		30	0.438	17.124	24.16	1.5993	4.712	4.48	718	359,000	82.06
		XS	0.500	17.000	27.49	1.5763	4.712	4.45	707	353,500	93.45
		40	0.562	16.876	30.79	1.5533	4.712	4.42	697	348,500	104.76
		60	0.750	16.500	40.64	1.4849	4.712	4.32	666	333,000	138.17
		80	0.938	16.124	50.28	1.4180	4.712	4.22	636	318,000	170.84
		100	1.156	15.688	61.17	1.3423	4.712	4.11	602	301,000	208.00
		120	1.375	15.250	71.82	1.2684	4.712	3.99	569	284,500	244.14
		140	1.562	14.876	80.66	1.2070	4.712	3.89	540	270,000	274.30
		160	1.781	14.438	90.75	1.1370	4.712	3.78	510	255,000	308.55
20	20	5S	0.188	19.624	11.70	2.1004	5.236	5.14	943	471,500	39.78
		10S	0.218	19.564	13.55	2.0878	5.236	5.12	937	467,500	46.06
		10	0.250	19.500	15.51	2.0740	5.236	5.11	930	465,500	52.73
		20, ST	0.375	19.250	23.12	2.0211	5.236	5.04	902	451,000	78.60
		30, XS	0.500	19.000	30.63	1.9689	5.236	4.97	883	441,500	104.13
		40	0.594	18.812	36.21	1.9302	5.236	4.92	866	433,000	123.06
		60	0.812	18.376	48.95	1.8417	5.236	4.81	826	413,000	166.50
		80	1.031	17.938	61.44	1.7550	5.236	4.70	787	393,500	208.92
		100	1.281	17.438	75.33	1.6585	5.236	4.57	744	372,000	256.15
		120	1.500	17.000	87.18	1.5763	5.236	4.45	707	353,500	296.37
		140	1.750	16.500	100.3	1.4849	5.236	4.32	665	332,500	341.10
		160	1.969	16.062	111.5	1.4071	5.236	4.21	632	316,000	379.14
24	24	5S	0.218	23.564	16.29	3.0285	6.283	6.17	1359	679,500	55.37
		10, 10S	0.250	23.500	18.65	3.012	6.283	6.15	1350	675,000	63.41
		20, ST	0.375	23.250	27.83	2.948	6.283	6.09	1325	662,500	94.62
		XS	0.500	23.000	36.90	2.885	6.283	6.02	1295	642,500	125.49
		30	0.562	22.876	41.39	2.854	6.283	5.99	1281	640,500	140.80
		40	0.688	22.624	50.39	2.792	6.283	5.92	1253	626,500	171.17
		60	0.969	22.062	70.11	2.655	6.283	5.78	1192	596,000	238.29
		80	1.219	21.562	87.24	2.536	6.283	5.64	1138	569,000	296.53
		100	1.531	20.938	108.1	2.391	6.283	5.48	1073	536,500	367.45
		120	1.812	20.376	126.3	2.264	6.283	5.33	1016	508,000	429.50
		140	2.062	19.876	142.1	2.155	6.283	5.20	965	482,500	483.24
		160	2.344	19.312	159.5	2.034	6.283	5.06	913	456,500	542.09
30	30	5S	0.250	29.500	23.37	4.746	7.854	7.72	2130	1,065,000	79.43
		10, 10S	0.312	29.376	29.10	4.707	7.854	7.69	2110	1,055,000	98.93
		ST	0.375	29.250	34.90	4.666	7.854	7.66	2094	1,048,000	118.65
		20, XS	0.500	29.000	46.34	4.587	7.854	7.59	2055	1,027,500	157.53
		30	0.625	28.750	57.68	4.508	7.854	7.53	2020	1,010,000	196.08

Table E.2 *Properties of Copper Water Tube, Types K, L, M*

Nominal Size	Actual Outside Diam. (in.)	Mean Outside Diam. Tolerances (in.): Soft Annealed	Mean Outside Diam. Tolerances (in.): Hard Drawn	Wall Thickness (in.) Type K: Nominal	Type K: Tolerance	Type L: Nominal	Type L: Tolerance	Type M: Nominal	Type M: Tolerance	Theoretical Weight (lb/ft): Type K	Type L	Type M
1/4	0.375	0.002	0.001	0.035	0.004	0.030	0.0035	—	—	0.145	0.126	
3/8	0.500	0.0025	0.001	0.049	0.004	0.035	0.0035	0.025	0.0025	0.269	0.198	0.145
1/2	0.625	0.0025	0.001	0.049	0.004	0.040	0.0035	0.028	0.0025	0.344	0.285	0.204
5/8	0.750	0.0025	0.001	0.049	0.004	0.042	0.0035	—	—	0.418	0.362	
3/4	0.875	0.003	0.001	0.065	0.0045	0.045	0.004	0.032	0.003	0.641	0.455	0.328
1	1.125	0.0035	0.0015	0.065	0.0045	0.050	0.004	0.035	0.0035	0.839	0.655	0.465
1 1/4	1.375	0.004	0.0015	0.065	0.0045	0.055	0.0045	0.042	0.0035	1.04	0.884	0.682
1 1/2	1.625	0.0045	0.002	0.072	0.005	0.060	0.0045	0.049	0.004	1.36	1.14	0.940
2	2.125	0.005	0.002	0.083	0.007	0.070	0.006	0.058	0.006	2.06	1.75	1.46
2 1/2	2.625	0.005	0.002	0.095	0.007	0.080	0.006	0.065	0.006	2.93	2.48	2.03
3	3.125	0.005	0.002	0.109	0.007	0.090	0.007	0.072	0.006	4.00	3.33	2.68
3 1/2	3.625	0.005	0.002	0.120	0.008	0.100	0.007	0.083	0.007	5.12	4.29	3.58
4	4.125	0.005	0.002	0.134	0.010	0.110	0.009	0.095	0.009	6.51	5.36	4.66
5	5.125	0.005	0.002	0.160	0.010	0.125	0.010	0.109	0.009	9.67	7.61	6.66
6	6.125	0.005	0.002	0.192	0.012	0.140	0.011	0.122	0.010	13.9	10.2	8.92
8	8.125	0.006	+ 0.002 − 0.004	0.271	0.016	0.200	0.014	0.170	0.014	25.9	19.3	16.5

Table E.3 *Properties of Copper and Red Brass Pipe*

A. Dimensions and Weights of Regular Pipe

Nominal Pipe Size (in.)	Nominal Dimensions (in.): Outside Diam.	Inside Diam.	Wall Thickness	Cross-Sectional Area of Bore (sq in.)	lb/ft: Red Brass	lb/ft: Copper	Nominal Pipe Size (in.)	Nominal Dimensions (in.): Outside Diam.	Inside Diam.	Wall Thickness	Cross-Sectional Area of Bore (sq in.)	lb/ft: Red Brass	lb/ft: Copper
1/8	0.405	0.281	0.062	0.062	0.253	0.259	2 1/2	2.875	2.501	0.187	4.91	5.99	6.12
1/4	0.540	0.376	0.082	0.110	0.447	0.457	3	3.500	3.062	0.219	7.37	8.56	8.75
3/8	0.675	0.495	0.090	0.192	0.627	0.641	3 1/2	4.000	3.500	0.250	9.62	11.2	11.4
1/2	0.840	0.626	0.107	0.307	0.934	0.955	4	4.500	4.000	0.250	12.6	12.7	12.9
3/4	1.050	0.822	0.114	0.531	1.27	1.30	5	5.562	5.062	0.250	20.1	15.8	16.2
1	1.315	1.063	0.126	0.887	1.78	1.82	6	6.625	6.125	0.250	29.5	19.0	19.4
1 1/4	1.660	1.368	0.146	1.47	2.63	2.69	8	8.625	8.001	0.312	50.3	30.9	31.6
1 1/2	1.900	1.600	0.150	2.01	3.13	3.20	10	10.750	10.020	0.365	78.8	45.2	46.2
2	2.375	2.063	0.156	3.34	4.12	4.22	12	12.750	12.000	0.375	113.0	55.3	56.5

B. Dimensions and Weights of Extra-Strong Pipe

Nominal Pipe Size (in.)	Nominal Dimensions (in.): Outside Diam.	Inside Diam.	Wall Thickness	Cross-Sectional Area of Bore (sq in.)	lb/ft: Red Brass	lb/ft: Copper	Nominal Pipe Size (in.)	Nominal Dimensions (in.): Outside Diam.	Inside Diam.	Wall Thickness	Cross-Sectional Area of Bore (sq in.)	lb/ft: Red Brass	lb/ft: Copper
1/8	0.405	0.205	0.100	0.033	0.363	0.371	2 1/2	2.875	2.315	0.280	4.21	8.66	8.85
1/4	0.540	0.294	0.123	0.068	0.611	0.625	3	3.500	2.892	0.304	6.57	11.6	11.8
3/8	0.675	0.421	0.127	0.139	0.829	0.847	3 1/2	4.000	3.358	0.321	8.86	14.1	14.4
1/2	0.840	0.542	0.149	0.231	1.23	1.25	4	4.500	3.818	0.341	11.5	16.9	17.3
3/4	1.050	0.736	0.157	0.425	1.67	1.71	5	5.562	4.812	0.375	18.2	23.2	23.7
1	1.315	0.951	0.182	0.710	2.46	2.51	6	6.625	5.751	0.437	26.0	32.2	32.9
1 1/4	1.660	1.272	0.194	1.27	3.39	3.46	8	8.625	7.625	0.500	45.7	48.4	49.5
1 1/2	1.900	1.494	0.203	1.75	4.10	4.19	10	10.750	9.750	0.500	74.7	61.1	62.4
2	2.375	1.933	0.221	2.94	5.67	5.80							

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