

APPENDIX A

Units

Appendix A-1a Conversion Factors for British Gravitational, English, and SI Units

Quantity	British Gravitational and English Units ^a	SI Unit ^a	Conversion Factor Equalities
Length	inch (in. or ")	<u>meter</u> (m)	*1 in. = 0.0254 m = 25.4 mm
	foot (ft or')	<u>meter</u> (m)	*1 ft = 0.3048 m = 304.8 mm
	<u>mile</u> (mi U.S. statute)	kilometer (km)	1 mile = 1.609 km = 1609 m
Volume	gallon (gal U.S.)	<u>meter</u> ³ (m ³)	1 gal = 0.003785 m ³ = 3.785 liters
Force (weight)	<u>pound</u> (lb)	newton ^d (N)	1 lb = 4.448 N
Torque	<u>pound-foot</u> (lb · ft)	newton-meter (N · m)	1 lb · ft = 1.356 N · m
Work, Energy	<u>foot-pound</u> (ft · lb)	joule ^e (J)	1 ft · lb = 1.356 J
Power	<u>foot-pound/second</u> (ft · lb/s)	watt ^g (W)	1 ft · lb/s = 1.356 W
	horsepower ^b (hp)	<u>kilowatt</u> (kW)	1 hp = 0.746 kW
Stress, Pressure	<u>pounds/in.²</u> (psi)	pascal ^c (Pa)	1 psi = 6895 Pa
	<u>thousand pounds/in.²</u> (ksi)	megapascal (MPa)	1 ksi = 6.895 MPa
Mass (British)	<u>slug</u> ^f	kilogram (kg)	1 slug = 14.59 kg
Mass (English)	lbm ^h	<u>kilogram</u> (kg)	1 lbm = 0.454 kg = 454 grams

^aThe *larger* unit is underlined.

^b 1 hp = 550 ft · lb/s; ^c 1 J = 1 N · m; ^d 1 N = 1 kg · m/s²; ^e 1 Pa = 1 N/m²; ^f 1 slug = 1 lb · s²/ft; ^g 1 W = 1 J/s; ^h 1 slug = 32.2 lbm

* An exact definition.

Appendix A-1b Conversion Factor Equalities Listed by Physical Quantity

ACCELERATION

$$*1 \text{ foot/second}^2 = 3.048 \times 10^{-1} \text{ meter/second}^2$$

$$*1 \text{ free fall, standard} = 9.806 65 \text{ meters/second}^2$$

$$*1 \text{ inch/second}^2 = 2.54 \times 10^{-2} \text{ meter/second}^2$$

AREA

$$*1 \text{ acre} = 4.046 856 422 4 \times 10^3 \text{ meters}^2$$

$$*1 \text{ foot}^2 = 9.290 304 \times 10^{-2} \text{ meter}^2$$

$$*1 \text{ hectare} = 1.00 \times 10^4 \text{ meters}^2$$

$$*1 \text{ inch}^2 = 6.4516 \times 10^{-4} \text{ meter}^2$$

$$*1 \text{ mile}^2 \text{ (U.S. statute)} = 2.589 988 110 336 \times 10^6 \text{ meters}^2$$

$$*1 \text{ yard}^2 = 8.361 273 6 \times 10^{-1} \text{ meter}^2$$

DENSITY

$$*1 \text{ gram/centimeter}^3 = 1.00 \times 10^3 \text{ kilograms/meter}^3$$

$$1 \text{ lbm/inch}^3 = 2.767 9905 \times 10^4 \text{ kilograms/meter}^3$$

$$1 \text{ lbm/foot}^3 = 1.601 846 3 \times 10^1 \text{ kilograms/meter}^3$$

$$1 \text{ slug/foot}^3 = 5.153 79 \times 10^2 \text{ kilograms/meter}^3$$

ENERGY

$$1 \text{ British thermal unit (mean)} = 1.055 87 \times 10^3 \text{ joules}$$

$$*1 \text{ erg} = 1.00 \times 10^{-7} \text{ joule}$$

$$1 \text{ foot-lb} = 1.355 817 9 \text{ joules}$$

$$*1 \text{ kilowatt-hour} = 3.60 \times 10^6 \text{ joules}$$

$$1 \text{ ton (nuclear equivalent of TNT)} = 4.20 \times 10^9 \text{ joules}$$

$$*1 \text{ watt-hour} = 3.60 \times 10^3 \text{ joules}$$

FORCE

$$*1 \text{ dyne} = 1.00 \times 10^{-5} \text{ newton}$$

$$*1 \text{ kilogram force (kgf)} = 9.806 65 \text{ newtons}$$

$$*1 \text{ kilopound force} = 9.806 65 \text{ newtons}$$

$$*1 \text{ kip} = 4.448 221 615 260 5 \times 10^3 \text{ newtons}$$

$$*1 \text{ lb (pound force, avoirdupois)} = 4.448 221 615 260 5 \text{ newtons}$$

$$1 \text{ ounce force (avoirdupois)} = 2.780 138 5 \times 10^{-1} \text{ newton}$$

$$*1 \text{ pound force, lb (avoirdupois)} = 4.448 221 615 260 5 \text{ newtons}$$

$$*1 \text{ poundal} = 1.382 549 543 76 \times 10^{-1} \text{ newton}$$

LENGTH

$$*1 \text{ angstrom} = 1.00 \times 10^{-10} \text{ meter}$$

$$*1 \text{ cubit} = 4.572 \times 10^{-1} \text{ meter}$$

$$*1 \text{ fathom} = 1.8288 \text{ meters}$$

$$*1 \text{ foot} = 3.048 \times 10^{-1} \text{ meter}$$

$$*1 \text{ inch} = 2.54 \times 10^{-2} \text{ meter}$$

$$*1 \text{ league (international nautical)} = 5.556 \times 10^3 \text{ meters}$$

$$1 \text{ light-year} = 9.460 55 \times 10^{15} \text{ meters}$$

$$*1 \text{ meter} = 1.650 763 73 \times 10^6 \text{ wavelengths Kr 86}$$

$$*1 \text{ micron} = 1.00 \times 10^{-6} \text{ meter}$$

$$*1 \text{ mil} = 2.54 \times 10^{-5} \text{ meter}$$

$$*1 \text{ mile (U.S. statute)} = 1.609 344 \times 10^3 \text{ meters}$$

$$*1 \text{ nautical mile (U.S.)} = 1.852 \times 10^3 \text{ meters}$$

$$*1 \text{ yard} = 9.144 \times 10^{-1} \text{ meter}$$

MASS

$$*1 \text{ carat (metric)} = 2.00 \times 10^{-4} \text{ kilogram}$$

$$*1 \text{ grain} = 6.479 891 \times 10^{-5} \text{ kilogram}$$

$$*1 \text{ lbm (pound mass, avoirdupois)} = 4.535 923 7 \times 10^{-1} \text{ kilogram}$$

$$*1 \text{ ounce mass (avoirdupois)} = 2.834 952 312 5 \times 10^{-2} \text{ kilogram}$$

$$1 \text{ slug} = 1.459 390 29 \times 10^1 \text{ kilograms}$$

$$*1 \text{ ton (long)} = 1.016 046 908 8 \times 10^3 \text{ kilograms}$$

$$*1 \text{ ton (metric)} = 1.00 \times 10^3 \text{ kilograms}$$

$$1 \text{ ton (short, 2000 pounds mass)} = 9.071 847 4 \times 10^2 \text{ kilograms}$$

Appendix A-1b (continued)**POWER**

- Btu (thermochemical)/second = $1.054\,350\,264\,488 \times 10^3$ watts
 *1 calorie (thermochemical)/second = 4.184 watts
 1 foot-lb/minute = $2.259\,696\,6 \times 10^{-2}$ watt
 1 foot-lb/second = 1.355 817 9 watts
 1 horsepower (550 foot-lb/second) = $7.456\,998\,7 \times 10^2$ watts
 *1 horsepower (electric) = 7.46×10^2 watts

PRESSURE

- *1 atmosphere = $1.013\,25 \times 10^5$ newtons/meter²
 *1 bar = 1.00×10^5 newtons/meter²
 1 centimeter of mercury (0°C) = $1.333\,22 \times 10^3$ newtons/meter²
 1 centimeter of water (4°C) = $9.806\,38 \times 10^1$ newtons/meter²
 *1 dyne/centimeter² = 1.00×10^{-1} newton/meter²
 1 inch of mercury (60°F) = $3.376\,85 \times 10^3$ newtons/meter²
 1 inch of water (60°F) = 2.4884×10^2 newtons/meter²
 *1 kgf/meter² = $9.806\,65$ newtons/meter²
 1 lb/foot² = $4.788\,025\,8 \times 10^1$ newtons/meter²
 1 lb/inch² (psi) = $6.894\,757\,2 \times 10^3$ newtons/meter²
 *1 millibar = 1.00×10^2 newtons/meter²
 1 millimeter of mercury (0°C) = $1.333\,224 \times 10^2$ newtons/meter²
 *1 pascal = 1.00 newtons/meter²
 1 psi (lb/inch²) = $6.894\,757\,2 \times 10^3$ newtons/meter²
 1 torr (0°C) = $1.333\,22 \times 10^2$ newtons/meter²

SPEED

- *1 foot/minute = 5.08×10^{-3} meter/second
 *1 foot/second = 3.048×10^{-1} meter/second
 *1 inch/second = 2.54×10^{-2} meter/second
 1 kilometer/hour = $2.777\,777\,8 \times 10^{-1}$ meter/second
 1 knot (international) = $5.144\,444\,444 \times 10^{-1}$ meter/second
 *1 mile/hour (U.S. statute) = 4.4704×10^{-1} meter/second

TEMPERATURE

- Celsius = kelvin - 273.15
 Fahrenheit = $\frac{9}{5}$ kelvin - 459.67
 Fahrenheit = $\frac{9}{5}$ Celsius + 32
 Rankine = $\frac{9}{5}$ kelvin

TIME

- *1 day (mean solar) = 8.64×10^4 seconds (mean solar)
 *1 hour (mean solar) = 3.60×10^3 seconds (mean solar)
 *1 minute (mean solar) = 6.00×10^1 seconds (mean solar)
 *1 month (mean calendar) = 2.628×10^6 seconds (mean solar)
 *1 year (calendar) = 3.1536×10^7 seconds (mean solar)

VISCOSITY

- *1 centistoke = 1.00×10^{-6} meter²/second
 *1 stoke = 1.00×10^{-4} meter²/second
 *1 foot²/second = $9.290\,304 \times 10^{-2}$ meter²/second
 *1 centipoise = 1.00×10^{-3} newton-second/meter²
 1 lbm/foot-second = $1.488\,163\,9$ newton-second/meter²
 1 lb-second/foot² = $4.788\,025\,8 \times 10^1$ newton-seconds/meter²
 *1 poise = 1.00×10^{-1} newton-second/meter²
 1 slug/foot-second = $4.788\,025\,8 \times 10^1$ newton-seconds/meter²

VOLUME

- 1 barrel (petroleum, 42 gallons) = $1.589\,873 \times 10^{-1}$ meter³
 *1 board foot (1 ft × 1 ft × 1 in.) = $2.359\,737\,216 \times 10^{-3}$ meter³
 *1 bushel (U.S.) = $3.523\,907\,016\,688 \times 10^{-2}$ meter³
 1 cord = $3.624\,556\,3$ meters³
 *1 cup = $2.365\,882\,365 \times 10^{-4}$ meter³

Appendix A-1b (continued)

*1 fluid ounce (U.S.) = 2.957 352 956 25 × 10 ⁻⁵ meter ³
*1 foot ³ = 2.831 684 659 2 × 10 ⁻² meter ³
*1 gallon (U.S. dry) = 4.404 883 770 86 × 10 ⁻³ meter ³
*1 gallon (U.S. liquid) = 3.785 411 784 × 10 ⁻³ meter ³
*1 inch ³ = 1.638 706 4 × 10 ⁻⁵ meter ³
*1 liter = 1.00 × 10 ⁻³ meter ³
*1 ounce (U.S. fluid) = 2.957 352 956 25 × 10 ⁻⁵ meter ³
*1 peck (U.S.) = 8.809 767 541 72 × 10 ⁻³ meter ³
*1 pint (U.S. dry) = 5.506 104 713 575 × 10 ⁻⁴ meter ³
*1 pint (U.S. liquid) = 4.731 764 73 × 10 ⁻⁴ meter ³
*1 quart (U.S. dry) = 1.101 220 942 715 × 10 ⁻³ meter ³
1 quart (U.S. liquid) = 9.463 529 5 × 10 ⁻⁴ meter ³
*1 stere = 1.00 meter ³
*1 tablespoon = 1.478 676 478 125 × 10 ⁻⁵ meter ³
*1 teaspoon = 4.928 921 593 75 × 10 ⁻⁶ meter ³
*1 ton (register) = 2.831 684 659 2 meters ³
*1 yard ³ = 7.645 548 579 84 × 10 ⁻¹ meter ³

* An exact definition.

Note: Spaces are sometimes used instead of commas to group numbers. This is to avoid confusion with the practice in some European countries of using commas for decimal points.

Source: E. A. Mechtly, *The International System of Units, Physical Constants and Conversion Factors*, NASA SP-7012, Scientific and Technical Information Office, National Aeronautics and Space Administration, Washington, D.C., 1973.

Appendix A-2a Standard SI Prefixes

Category	Name	Symbol	Factor
Recommended, important for this course.	giga	G	1 000 000 000 = 10 ⁹
	mega	M	1 000 000 = 10 ⁶
	kilo	k	1 000 = 10 ³
	milli	m	0.001 = 10 ⁻³
	micro	μ	0.000 001 = 10 ⁻⁶
Not recommended but sometimes encountered.	hecto	h	100 = 10 ²
	deca	da	10 = 10 ¹
	deci	d	0.1 = 10 ⁻¹
	centi	c	0.01 = 10 ⁻²
Not encountered in this course.	tera	T	1 000 000 000 000 = 10 ¹²
	nano	n	0.000 000 000 = 10 ⁻⁹
	pico	p	0.000 000 000 000 = 10 ⁻¹²
	femto	f	0.000 000 000 000 000 = 10 ⁻¹⁵
	atto	a	0.000 000 000 000 000 000 = 10 ⁻¹⁸

Note: Spaces are sometimes used instead of commas to group numbers. This is to avoid confusion with the practice in some European countries of using commas for decimal points.

Appendix A-2b SI Units and Symbols

Quantity	Name	Symbol	Expressed in Other Units
Length ^a	meter	m	
Mass ^a	kilogram	kg	
Time ^a	second	s	
Temperature ^{a,b}	kelvin	K	
Plane angle ^c	radian	rad	
Acceleration	meter per second squared	m/s ²	
Angular acceleration	radian per second squared	rad/s ²	
Angular velocity	radian per second	rad/s	
Area	square meter	m ²	
Density	kilogram per cubic meter	kg/m ³	
Energy	joule	J	N · m
Force	newton	N	m · kg · s ⁻²
Frequency	hertz	Hz	s ⁻¹
Heat, quantity of	joule	J	N · m
Moment of force	newton-meter	N · m	
Power	watt	W	J/s
Pressure	pascal	Pa	N/m ²
Specific heat capacity	joule per kilogram kelvin	J/(kg · K)	
Speed	meter per second	m/s	
Thermal conductivity	watt per meter kelvin	W/(m · K)	
Velocity	meter per second	m/s	
Viscosity, dynamic	pascal-second	Pa · s	
Volume	cubic meter	m ³	
Work	joule	J	N · m

^aSI base unit.

^bCelsius temperature is expressed in degrees Celsius (symbol °C).

^cSupplementary unit.

Source: Chester H. Page and Paul Vigoureux, eds., *The International System of Units (SI)*, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Order by SD Catalog No. C13.10 : 330/2), National Bureau of Standards Special Publications 330, 1972, p. 12.

Appendix A-3 Suggested SI Prefixes for Stress Calculations

$$\sigma = \frac{P}{A}, \frac{Mc}{I}, \frac{M}{Z}; \tau = \frac{P}{A}, \frac{V}{A}, \frac{Tr}{J}, \frac{T}{Z'}, \frac{V}{Ib} \int dA$$

σ, τ	P, V	M, T	A	I, J	c, r, b, y	Z, Z'
Pa	N	N · m	m ²	m ⁴	m	m ³
kPa	kN	kN · m	m ²	m ⁴	m	m ³
MPa	N	N · mm	mm ²	mm ⁴	mm	mm ³
GPa	kN	N · m	mm ²	mm ⁴	mm	mm ³

Appendix A-4 Suggested SI Prefixes for Linear-Deflection Calculations

$$\delta = \frac{PL^a}{AE}; \delta \propto \frac{PL^3}{EI}, \frac{wL^4}{EI}, \frac{ML^2}{EI}$$

δ	P	w	M	L	A	E	I
μm	N	N/m	N · m	m	m ²	MPa	m ⁴
μm	N	N/mm	N · mm	mm	mm ²	GPa	mm ⁴
μm	kN	N/m	kN · m	m	m ²	GPa	m ⁴

^aIllustrated in Table 5.1.**Appendix A-5 Suggested SI Prefixes for Angular-Deflection Calculations**

$$\theta = \frac{TL^a}{K'G}, \frac{ML^a}{IE}$$

θ	T, M	L	K', I	E, G
rad	N · m	m	m ⁴	Pa
μrad	N · m	m	m ⁴	MPa
mrad	N · mm	mm	mm ⁴	GPa
μrad	kN · m	m	m ⁴	GPa

^aIllustrated in Table 5.1.