Ninth Edition

Roark's Formulas for Stress and Strain

Richard G. Budynas and Ali M. Sadegh

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About the Authors

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Preface to the Ninth Edition

It is recognized that recent high-powered computers incorporated in computational mechanics such as finite element methods have advanced and facilitated design and stress and strain analyses of mechanical and structural systems. While numerical methods are widely used in engineering practice, the very essence of engineering is rooted in the power of classical closed-form solutions and established analytical methods. In addition, for optimization, parametric design, and for understanding the mechanical behavior of a system, a closed-form analytical solution is advantageous to a numerical solution.

Since the publication of the 8th edition of *Roark's Formulas for Stress and Strain*, 10 years ago, we have witnessed significant advances in engineering methodology in solving stress analysis problems. This has motivated the authors to embark on an improved edition of this book.

Thus in preparation of this 9th edition, the authors had three continuing objectives: first, to modernize with newly designed artwork and update the contents as required, second, to introduce new topics and chapters that will maintain the high standard of this book, and finally, to improve upon the material retained from the 8th edition. The 9th edition of Roark's is intended to make available a compact, comprehensive summary of the formulas and principles pertaining to strength of materials for both practicing engineers and engineering students.

This book is intended primarily to be a reference book that is authoritative and covers the field of stress and strain analyses in a comprehensive manner. Similar to the 8th edition, the tabular format is continued in this edition. This format has been particularly successful when implementing problem solutions on user-friendly computer software such as MATLAB, MathCAD, TK Solver, and Excel. Commercial packages are available which integrate the abovementioned software with Roark's. Tabulated coefficients are in dimensionless form for convenience in using either system of units. Design formulas drawn from works published in the past remain in the system units originally published or quoted.

The authors are mindful of the competing requirements to offer the user a broad spectrum of information that has made this book so useful for over 80 years. Therefore, in this edition, the authors have included a number of new topics in the chapters. The main organizational change in the 9th edition is that majority of tables are published in portrait format for ease of reading. Other changes/additions included in the 9th edition are as follows:

- Chapter 2, Stress and Strain: Important Relationships: A new section on three-dimensional Mohr's circle analysis for simple configurations is added.
- Chapter 3, The Behavior of Bodies under Stress: Mechanical properties of some constructional steel including modulus of elasticity of materials and yield strength are added. In addition, a section on factor of safety is also added.
- Chapter 4, Principles and Analytical Methods: The energy method "Castigliano's theorem" for deflections calculation is revised, and more examples are added.
- Chapter 5, Numerical Methods: The numerical methods "finite element method" and "boundary element method" with more references are updated and revised.

- Chapter 6, Experimental Methods: A new section "Nondestructive Testing" for quantitatively characterizing mechanical properties is added.
- Chapter 16, Dynamic and Temperature Stresses: Tables of natural frequencies of cylindrical shells and springs are added.
- Chapter 17, Stress Concentration: The table for stress concentration factor is expanded.
- Chapter 18, Fatigue and Fracture: A new section on fatigue with a table of fatigue limits of materials and a new section on creep with a table of creep of materials at high temperature are added.
- Chapter 19, Stresses in Fasteners, Joints, and Gears: A new section "Bolt Strength and Design" and a new section Gearing and Gear Stress are added.
- Chapter 20, Composite Materials: Two new sections "Composite Sandwich Structures" and "Composite Cellular Structures" are added. In addition, a table of Mechanical Properties of Graphite-Polymer Composite Material with Different Volume Fraction and several new references are added.
- Chapter 21, Solid Biomechanics: Biomechanics is updated and revised, and artificial intervertebral discs are discussed.
- The references and publications of most chapters are expanded and updated.
- All the chapters are redesigned to make a much better user experience including: adding color to the figures and tables; newly designed artwork and headings; and portrait format of majority of tables for ease of reading.

The authors would especially like to thank those individuals, publishers, institutions, and corporations who have generously given permission to use material in this and previous editions, and the many dedicated readers and users of *Roark's Formulas for Stress and Strain*.

Meticulous care has been exercised to avoid errors. However, if any are inadvertently included in this newly designed printing, the authors will appreciate being informed so that these errors can be eliminated in subsequent printings of this edition.

Richard G. Budynas
Ali M. Sadegh

Preface to the First Edition

This book was written for the purpose of making available a compact, adequate summary of the formulas, facts, and principles pertaining to strength of materials. It is intended primarily as a reference book and represents an attempt to meet what is believed to be a present need of the designing engineer.

This need results from the necessity for more accurate methods of stress analysis imposed by the trend of engineering practice. That trend is toward greater speed and complexity of machinery, greater size and diversity of structures, and greater economy and refinement of design. In consequence of such developments, familiar problems, for which approximate solutions were formerly considered adequate, are now frequently found to require more precise treatment, and many less familiar problems, once of academic interest only, have become of great practical importance. The solutions and data desired are often to be found only in advanced treatises or scattered through an extensive literature, and the results are not always presented in such form as to be suited to the requirements of the engineer. To bring together as much of this material as is likely to prove generally useful and to present it in convenient form have been the author's aim.

The scope and management of the book are indicated by the contents. In Part 1 are defined all terms whose exact meanings might otherwise not be clear. In Part 2 certain useful general principles are stated; analytical and experimental methods of stress analysis are briefly described; and information concerning the behavior of material under stress is given. In Part 3 the behavior of structural elements under various conditions of loading is discussed, and extensive tables of formulas for the calculation of stress, strain, and strength are given.

Because they are not believed to serve the purpose of this book, derivations of formulas and detailed explanations, such as are appropriate in a textbook, are omitted, but a sufficient number of examples are included to illustrate the application of the various formulas and methods. Numerous references to more detailed discussions are given, but for the most part these are limited to sources that are generally available, and no attempt has been made to compile an exhaustive bibliography.

That such a book as this derives almost wholly from the work of others is self-evident, and it is the author's hope that due acknowledgment has been made of the immediate sources of all material presented here. To the publishers and others who have generously permitted the use of material, he wishes to express his thanks. The helpful criticisms and suggestions of his colleagues, Professors E. R. Maurer, M. O. Withey, J. B. Kommers, and K. F. Wendt, are gratefully acknowledged. A considerable number of the tables of formulas have been published from time to time in *Product Engineering*, and the opportunity thus afforded for criticism and study of arrangement has been of great advantage.

Finally, it should be said that, although every care has been taken to avoid errors, it would be oversanguine to hope that none had escaped detection; for any suggestions that readers may make concerning needed corrections, the author will be grateful.

Raymond J. Roark

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List of Tables

Roark's Formulas for Stress and Strain

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CHAPTER 1

Introduction

The widespread use of personal computers, which have the power to solve problems solvable in the past only on mainframe computers, has influenced the tabulated format of this book. Computer programs for structural analysis, employing techniques such as the finite element method and the boundary element method, are also available for general use. These programs are very powerful; however, in many cases, elements of structural systems can be analyzed quite effectively independently without the need for an elaborate finite element model. In some instances, finite element models or programs are verified by comparing their solutions with the results given in a book such as this. Contained within this book are simple, accurate, and thorough tabulated formulations that can be applied to the stress analysis of a comprehensive range of structural components.

This chapter serves to introduce the reader to the terminology, state property units and conversions, and contents of the book.

1.1 TERMINOLOGY

Definitions of terms used throughout the book can be found in the glossary in App. C.

1.2 STATE PROPERTIES, UNITS, AND CONVERSIONS

The basic state properties associated with stress analysis include the following: geometrical properties such as length, area, volume, centroid, center of gravity, and second-area moment (area moment of inertia); material properties such as mass density, modulus of elasticity, Poisson's ratio, and thermal expansion coefficient; loading properties such as force, moment, and force distributions (e.g., force per unit length, force per unit area, and force per unit volume); other properties associated with loading, including energy, work, and power; and stress analysis properties such as deformation, strain, and stress.

Two basic systems of units are employed in the field of stress analysis: SI units and USCU units.* SI units are mass-based units using the kilogram (kg), meter (m), second (s), and Kelvin (K) or degree Celsius (°C) as the fundamental units of mass, length, time, and temperature, respectively. Other SI units, such as that used for force, the Newton (kg-m/s^2), are derived quantities. USCU units are force-based units using the pound force (lbf),

*SI and USCU are abbreviations for the International System of Units (from the French Systéme International d'Unités) and the United States Customary Units, respectively.

TABLE 1.1 Units Appropriate to Structural Analysis*

Quantity	International Metric (SI)	U.S. Customary
Length	(meter) m	(foot) ft
Force and weight, *W*	(newton) N(kg-m/s^2)	(pound) lbf
Time	s	s
Angle	rad	rad
Second area moment	m^4	ft^4
Mass	kg	lbf-s^2/ft (slug)
Area	m^2	ft^2
Mass moment of inertia	kg-m^2	lbf-s^2-ft
Moment	N-m	lbf-ft
Volume	m^3	ft^3
Mass density	kg/m^3	lbf-s^2/ft^4
Stiffness of linear spring	N/m	lbf/ft
Stiffness of rotary spring	N-m/rad	lbf-ft/rad
Temperature	K (Kelvin)	°F (degrees Fahrenheit)
Torque, work, energy	N-m (Joule)	lbf-ft
Stiffness of torsional spring	N-m/rad	lbf-ft/rad
Stress or pressure	N/m^2 (pascal)	lbf/ft^2 (psi)

*In stress anlaysis, the unit of length used most often is the inch.

inch (in) or foot (ft), second (s), and degree Fahrenheit (°F) as the fundamental units of force, length, time, and temperature, respectively. Other USCU units, such as that used for mass, the slug (lbf-s^2/ft) or the nameless lbf-s^2/in, are derived quantities. Table 1.1 gives a listing of the primary SI and USCU units used for structural analysis. Other SI units are given in Table 1.2. Certain prefixes may be appropriate, depending on the size of the quantity. Common prefixes are given in Table 1.3. For example, the modulus of elasticity of carbon steel is approximately 207 GPa = 207×10^9 Pa = 207×10^9 N/m^2. Prefixes are normally used with SI units. However, there are cases where prefixes are also used with USCU units. Some examples are the kpsi (1 kpsi = 10^3 psi = 10^3 lbf/in^2), kip (1 kip = 1 kilopound = 1,000 lbf), and Mpsi (1 Mpsi = 10^6 psi).

Depending on the application, different units may be specified. It is important that the analyst be aware of all the implications of the units and make consistent use of them. For example, if you are building a model from a CAD file in which the design dimensional units are given in mm, it is unnecessary to change the system of units or to scale the model to units of m. However, if in this example the input forces are in Newtons, then the output stresses will be in N/mm^2, which is correctly expressed as MPa. If in this example applied moments are to be specified, the units should be N-mm. For deflections in this example, the modulus of elasticity E should also be specified in MPa and the output deflections will be in mm.

Tables 1.4 and 1.5 present the conversions from USCU units to SI units and vice versa for some common state property units. The more detailed conversion units are given in Table 1.6.

TABLE 1.2 SI Units

Quantity	Unit (SI)	Formula
Base Units		
Length	meter (m)	
Mass	kilogram (kg)	
Time	second (s)	
Thermodynamic temperature	Kelvin (K)	
Supplementary Units		
Plane angle	radian (rad)	
Solid angle	steradian (sr)	
Derived Units		
Acceleration	meter per second square	m/s^2
Angular acceleration	radian per second square	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)	$kg\text{-}m/s^2$
Frequency	hertz (Hz)	1/s
Power	watt (W)	J/s
Pressure	Pascal (Pa)	N/m^2
Quantity of heat	joule (J)	N-m
Stress	Pascal (Pa)	N/m^2
Thermal conductivity	watt per meter-Kelvin	W/(m-K)
Velocity	meter per second	m/s
Viscosity dynamic	Pascal-second	Pa-s
Viscosity kinematic	square meter per second	m^2/s
Work	joule (J)	N-m

1.3 CONTENTS

Following the introduction, the state of stress and the important relationships associated with stress and strain and their transformations including Mohr's circle is described in Chap. 2. The behavior of bodies under stress is presented in Chap. 3. Chapter 4 describes equation of motion and equilibrium of solid and analytical methods of solving for the stresses and deflections in an elastic body, including the energy methods. Numerical methods such as Finite Element Method and Boundary Element Method are presented in Chap. 5. The experimental methods for stress and strain measurements are presented in Chap. 6. Many topics associated with the stress analysis of structural components, including direct tension, compression, shear, and combined stresses; bending of straight and curved beams; torsion; bending of flat plates; columns and other compression members; shells of revolution, pressure vessels, and pipes; direct bearing and shear stress; elastic stability;

TABLE 1.3 Multiples and Submultiples of SI Units

Prefix	Symbol		Multiplying Factor
exa	E	10^{18}	1 000 000 000 000 000 000
peta	P	10^{15}	1 000 000 000 000 000
tera	T	10^{12}	1 000 000 000 000
giga	G	10^{9}	1 000 000 000
mega	M	10^{6}	1 000 000
kilo	k	10^{3}	1 000
hecto	h	10^{2}	100
deca	da	10	10
deci	d	10^{-1}	0.1
centi	c	10^{-2}	0.01
milli	m	10^{-3}	0.001
micro	µ	10^{-6}	0.000 001
nano	n	10^{-9}	0.000 000 001
pico	p	10^{-12}	0.000 000 000 001
femto	f	10^{-15}	0.000 000 000 000 001
atto	a	10^{-18}	0.000 000 000 000 000 001

TABLE 1.4 SI Conversion Table

SI Units	From SI to English	From English to SI
Length		
kilometer (km) = 1000 m	1 km = 0.621 mi	1 mi = 1.609 km
meter (m) = 100 cm	1 m = 3.281 ft	1 ft = 0.305 m
centimeter (cm) = 0.01 m	1 cm = 0.394 in	1 in = 2.540 cm
millimeter (mm) = 0.001 m	1 mm = 0.039 in	1 in = 25.4 mm
micrometer (µm) = 0.000 001 m	1 µm = 3.93×10^{-5} in	1 in = 25,400 mm
nanometer (nm) = 0.000 000 001 m	1 nm = 3.93×10^{-8} in	1 in = 25,400,000 mm
Area		
square kilometer (km^2) = 100 hectares	1 km^2 = 0.386 mi^2	1 mi^2 = 2.590 km^2
hectare (ha) = 10,000 m^2	1 ha = 2.471 acres	1 acre = 0.405 ha
square meter (m^2) = 10,000 cm^2	1 m^2 = 10.765 ft^2	1 ft^2 = 0.093 m^2
square centimeter (cm^2) = 100 mm^2	1 cm^2 = 0.155 in^2	1 in^2 = 6.452 cm^2
Volume		
liter (L) = 1000 mL = 1 dm^3	1 L = 1.057 fl qt	1 fl qt = 0.946 L
milliliter (mL) = 0.001 L = 1 cm^3	1 mL = 0.034 fl oz	1 fl oz = 29.575 mL
microliter (µL) = 0.000 001 L	1 µL = 3.381×10^{-5} fl oz	1 fl oz = 29,575 µL

(*Continued*)

TABLE 1.4 SI Conversion Table (*Continued*)

SI Units	From SI to English	From English to SI
Mass		
kilogram (kg) = 1000 g	1 kg = 2.205 lb	1 lb = 0.454 kg
gram (g) = 1000 mg	1 g = 0.035 oz	1 oz = 28.349 g
milligram (mg) = 0.001 g	1 mg = 3.52×10^{-5} oz	1 oz = 28,349 mg
microgram (µg) = 0.000 001 g	1 µg = 3.52×10^{-8} oz	1 oz = 28,349,523 µg

TABLE 1.5 Multiplication Factors to Convert from USCU Units to SI Units

To Convert from	To	Multiply by
Mass		
ounce (avoirdupois)	kilogram (kg)	2.834952×10^{-2}
pound (avoirdupois)	kilogram (kg)	4.535924×10^{-1}
ton (short, 2000 lb)	kilogram (kg)	9.071847×10^{2}
ton (long, 2240 lb)	kilogram (kg)	1.016047×10^{3}
kilogram (kg)	ounce (avoirdupois)	3.527396×10^{1}
kilogram (kg)	pound (avoirdupois)	2.204622
kilogram (kg)	ton (short, 2000 lb)	1.102311×10^{-3}
kilogram (kg)	ton (long, 2240 lb)	9.842064×10^{-4}
Mass Per Unit Length		
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488164
pound per inch (lb/in)	kilogram per meter (kg/m)	1.785797×10^{1}
kilogram per meter (kg/m)	pound per foot (lb/ft)	6.719689×10^{-1}
kilogram per meter (kg/m)	pound per inch (lb/in)	5.599741×10^{-2}
Mass Per Unit Area		
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882428
kilogram per square meter (kg/m^2)	pound per square foot (lb/ft^2)	2.048161×10^{-1}
Mass Per Unit Volume		
pound per cubic foot (lb/ft^3)	kilogram per cubic meter (kg/m^3)	1.601846×10^{1}
pound per cubic inch (lb/in^3)	kilogram per cubic meter (kg/m^3)	2.767990×10^{4}
kilogram per cubic meter (kg/m^3)	pound per cubic foot (lb/ft^3)	6.242797×10^{-2}
kilogram per cubic meter (kg/m^3)	pound per cubic inch (lb/in^3)	3.612730×10^{-5}
pound per cubic foot (lb/ft^3)	pound per cubic inch (lb/in^3)	1.728000×10^{3}
Length		
foot (ft)	meter (m)	3.048000×10^{-1}
inch (in)	meter (m)	2.540000×10^{-2}
mil	meter (m)	2.540000×10^{-5}
inch (in)	micrometer (µm)	2.540000×10^{4}
meter (m)	foot (ft)	3.28084
meter (m)	inch (in)	3.937008×10^{1}
meter (m)	mil	3.937008×10^{4}
micrometer (µm)	inch (in)	3.937008×10^{-5}

(*Continued*)

TABLE 1.5 Multiplication Factors to Convert from USCU Units to SI Units (*Continued*)

To Convert from	To	Multiply by
Area		
$foot^2$	square meter (m^2)	9.290304×10^{-2}
$inch^2$	square meter (m^2)	6.451600×10^{-4}
circular mil	square meter (m^2)	5.067075×10^{-10}
square centimeter (cm^2)	square inch (in^2)	1.550003×10^{-1}
square meter (m^2)	$foot^2$	1.076391×10^{1}
square meter (m^2)	$inch^2$	1.550003×10^{3}
square meter (m^2)	circular mil	1.973525×10^{9}
Volume		
$foot^3$	cubic meter (m^3)	2.831685×10^{-2}
$inch^3$	cubic meter (m^3)	1.638706×10^{-5}
cubic centimeter (cm^3)	cubic inch (in^3)	6.102374×10^{-2}
cubic meter (m^3)	$foot^3$	3.531466×10^{1}
cubic meter (m^3)	$inch^3$	6.102376×10^{4}
gallon (U.S. liquid)	cubic meter (m^3)	3.785412×10^{-3}
Force		
pounds-force (lbf)	newtons (N)	4.448222
Pressure or Stress		
pound force per square inch (lbf/in^2)(psi)	pascal (Pa)	6.894757×10^{3}
kip per square inch (kip/in^2)(ksi)	pascal (Pa)	6.894757×10^{6}
pound force per square inch (lbf/in^2)(psi)	megapascal (MPa)	6.894757×10^{-3}
pascal (Pa)	pound force per square inch (psi)	1.450377×10^{-4}
pascal (Pa)	kip per square inch (ksi)	1.450377×10^{-7}
megapascals (MPa)	pound force per square inch (lbf/in^2) (psi)	1.450377×10^{2}
Section Properties		
section modulus S (in^3)	S (m^3)	1.638706×10^{-5}
moment of inertia I (in^4)	I (m^4)	4.162314×10^{-7}
modulus of elasticity E (psi)	E (Pa)	6.894757×10^{3}
section modulus S (m^3)	S (in^3)	6.102374×10^{4}
moment of inertia I (m^4)	I (in^4)	2.402510×10^{6}
modulus of elasticity E (Pa)	E (psi)	1.450377×10^{-4}
Temperature		
degree Fahrenheit	degree Celsius	$t°C = (t°F - 32)/1.8$
degree Celsius	degree Fahrenheit	$t°F = 1.8\,t°C + 32$
Angle		
degree	radian (rad)	1.745329×10^{-2}
radian (rad)	degree	5.729578×10^{1}

TABLE 1.6 Conversion Factors

To Convert from	To	Multiply by
acceleration of free fall, standard (g_n)	meter per second square (m/s^2)	9.80665
acre (based on U.S. survey foot)	square meter (m^2)	4.046873×10^3
acre foot (based on U.S. survey foot)	cubic meter (m^3)	1.233489×10^3
atmosphere, standard (atm)	pascal (Pa)	1.01325×10^5
atmosphere, standard (atm)	kilopascal (kPa)	1.01325×10^2
atmosphere, technical (at)	pascal (Pa)	9.80665×10^4
atmosphere, technical (at)	kilopascal (kPa)	9.80665×10^1
bar (bar)	pascal (Pa)	1.0×10^5
bar (bar)	kilopascal (kPa)	1.0×10^2
barn (b)	square meter (m^2)	1.0×10^{-28}
barrel [for petroleum, 42 gallons (U.S.)] (bbl)	cubic meter (m^3)	1.589873×10^{-1}
barrel [for petroleum, 42 gallons (U.S.)] (bbl)	liter (L)	1.589873×10^2
$calorie_{IT}$ (cal_{IT})	joule (J)	4.1868
$calorie_{th}$ (cal_{th})	joule (J)	4.184
calorie (cal) (mean)	joule (J)	4.19002
calorie (15°C) (cal_{15})	joule (J)	4.18580
calorie (20°C) (cal_{20})	joule (J)	4.18190
centimeter of mercury (0°C)	pascal (Pa)	1.33322×10^3
centimeter of mercury (0°C)	kilopascal (kPa)	1.33322
centimeter of mercury, conventional (cmHg)	pascal (Pa)	1.333224×10^3
centimeter of mercury, conventional (cmHg)	kilopascal (kPa)	1.333224
centimeter of water (4°C)	pascal (Pa)	9.80638×10^1
centimeter of water, conventional (cmH_2O)	pascal (Pa)	9.80665×10^1
centipoise (cP)	pascal second (Pa-s)	1.0×10^{-3}
centistokes (cSt)	meter square per second (m^2/s)	1.0×10^{-6}
chain (based on U.S. survey foot) (ch)	meter (m)	2.011684×10^1
circular mil	square meter (m^2)	5.067075×10^{-10}
cubic foot (ft^3)	cubic meter (m^3)	2.831685×10^{-2}
cubic foot per minute (ft^3/min)	cubic meter per second (m^3/s)	4.719474×10^{-4}
cubic foot per minute (ft^3/min)	liter per second (L/s)	4.719474×10^{-1}
cubic foot per second (ft^3/s)	cubic meter per second (m^3/s)	2.831685×10^{-2}
cubic inch (in^3)	cubic meter (m^3)	1.638706×10^{-5}

(*Continued*)

TABLE 1.6 Conversion Factors (*Continued*)

To Convert from	To	Multiply by
cubic inch per minute (in^3/min)	cubic meter per second (m^3/s)	2.731177×10^{-7}
cubic mile (mi^3)	cubic meter (m^3)	4.168182×10^{9}
cubic yard (yd^3)	cubic meter (m^3)	7.645549×10^{-1}
cubic yard per minute (yd^3/min)	cubic meter per second (m^3/s)	1.274258×10^{-2}
cup (U.S.)	cubic meter (m^3)	2.365882×10^{-4}
cup (U.S.)	liter (L)	2.365882×10^{-1}
cup (U.S.)	milliliter (mL)	2.365882×10^{2}
day (d)	second (s)	8.64×10^{4}
day (sidereal)	second (s)	8.616409×10^{4}
degree (angle) (°)	radian (rad)	1.745329×10^{-2}
degree Celsius (temperature) (°C)	kelvin (K)	$T/K = t/°C + 273.15$
degree Celsius (temperature interval) (°C)	kelvin (K)	1.0
degree centigrade (temperature)	degree Celsius (°C)	$t/°C \approx t/\text{deg. cent.}$
degree centigrade (temperature interval)	degree Celsius (°C)	1.0
degree Fahrenheit (temperature) (°F)	degree Celsius (°C)	$t/°C = (t/°F - 32)/1.8$
degree Fahrenheit (temperature) (°F)	kelvin (K)	$T/K = (t/°F + 459.67)/1.8$
dyne (dyn)	newton (N)	1.0×10^{-5}
dyne centimeter (dyn-cm)	newton meter (N-m)	1.0×10^{-7}
dyne per square centimeter (dyn/cm^2)	pascal (Pa)	1.0×10^{-1}
fermi	femtometer (fm)	1.0
fluid ounce (U.S.) (fl oz)	cubic meter (m^3)	2.957353×10^{-5}
fluid ounce (U.S.) (fl oz)	milliliter (mL)	2.957353×10^{1}
foot (ft)	meter (m)	3.048×10^{-1}
foot (U.S. survey) (ft)	meter (m)	3.048006×10^{-1}
foot of mercury, conventional (ftHg)	pascal (Pa)	4.063666×10^{4}
foot of mercury, conventional (ftHg)	kilopascal (kPa)	4.063666×10^{1}
foot of water (39.2°F)	pascal (Pa)	2.98898×10^{3}
foot of water (39.2°F)	kilopascal (kPa)	2.98898
foot of water, conventional (ftH_2O)	pascal (Pa)	2.989067×10^{3}
foot of water, conventional (ftH_2O)	kilopascal (kPa)	2.989067
foot per hour (ft/h)	meter per second (m/s)	8.466667×10^{-5}
foot per minute (ft/min)	meter per second (m/s)	5.08×10^{-3}
foot per second (ft/s)	meter per second (m/s)	3.048×10^{-1}
foot per second square (ft/s^2)	meter per second square (m/s^2)	3.048×10^{-1}

(*Continued*)

TABLE 1.6 Conversion Factors (*Continued*)

To Convert from	To	Multiply by
foot poundal	joule (J)	4.214011×10^{-2}
foot pound-force (ft-lbf)	joule (J)	1.355818
foot pound-force per hour (ft-lbf/h)	watt (W)	3.766161×10^{-4}
foot pound-force per minute (ft-lbf/min)	watt (W)	2.259697×10^{-2}
foot pound-force per second (ft-lbf/s)	watt (W)	1.355818
foot to the fourth power (ft^4)	meter to the fourth power (m^4)	8.630975×10^{-3}
gal (gal)	meter per second square (m/s^2)	1.0×10^{-2}
gallon [Canadian and U.K. (Imperial)] (gal)	cubic meter (m^3)	4.54609×10^{-3}
gallon [Canadian and U.K. (Imperial)] (gal)	liter (L)	4.54609
gallon (U.S.) (gal)	cubic meter (m^3)	3.785412×10^{-3}
gallon (U.S.) (gal)	liter (L)	3.785412
gallon (U.S.) per day (gal/d)	cubic meter per second (m^3/s)	4.381264×10^{-8}
gallon (U.S.) per day (gal/d)	liter per second (L/s)	4.381264×10^{-5}
gallon (U.S.) per horsepower hour [gal/(hp-h)]	cubic meter per joule (m^3/J)	1.410089×10^{-9}
gallon (U.S.) per horsepower hour [gal/(hp-h)]	liter per joule (L/J)	1.410089×10^{-6}
gallon (U.S.) per minute (gpm)(gal/min)	cubic meter per second (m^3/s)	6.309020×10^{-5}
gallon (U.S.) per minute (gpm)(gal/min)	liter per second (L/s)	6.309020×10^{-2}
gon (also called grade) (gon)	radian (rad)	1.570796×10^{-2}
gon (also called grade) (gon)	degree (angle) (°)	9.0×10^{-1}
grain (gr)	kilogram (kg)	6.479891×10^{-5}
grain (gr)	milligram (mg)	6.479891×10^{1}
grain per gallon (U.S.) (gr/gal)	kilogram per cubic meter (kg/m^3)	1.711806×10^{-2}
grain per gallon (U.S.) (gr/gal)	milligram per liter (mg/L)	1.711806×10^{1}
gram-force per square centimeter (gf/cm^2)	pascal (Pa)	9.80665×10^{1}
gram per cubic centimeter (g/cm^3)	kilogram per cubic meter (kg/m^3)	1.0×10^{3}
hectare (ha)	square meter (m^2)	1.0×10^{4}
horsepower (550 ft-lbf/s) (hp)	watt (W)	7.456999×10^{2}
horsepower (boiler)	watt (W)	9.80950×10^{3}
horsepower (electric)	watt (W)	7.46×10^{2}
horsepower (metric)	watt (W)	7.354988×10^{2}

(*Continued*)

TABLE 1.6 Conversion Factors (*Continued*)

To Convert from	To	Multiply by
horsepower (U.K.)	watt (W)	7.4570×10^2
horsepower (water)	watt (W)	7.46043×10^2
hour (h)	second (s)	3.6×10^3
inch (in)	meter (m)	2.54×10^{-2}
inch (in)	centimeter (cm)	2.54
inch of mercury (32°F)	pascal (Pa)	3.38638×10^3
inch of mercury (32°F)	kilopascal (kPa)	3.38638
inch of mercury (60°F)	pascal (Pa)	3.37685×10^3
inch of mercury (60°F)	kilopascal (kPa)	3.37685
inch of mercury, conventional (inHg)	pascal (Pa)	3.386389×10^3
inch of mercury, conventional (inHg)	kilopascal (kPa)	3.386389
inch of water (39.2°F)	pascal (Pa)	2.49082×10^2
inch of water (60°F)	pascal (Pa)	2.4884×10^2
inch of water, conventional (inH_2O)	pascal (Pa)	2.490889×10^2
inch per second (in/s)	meter per second (m/s)	2.54×10^{-2}
kelvin (K)	degree Celsius (°C)	$t/°C = T/K - 273.15$
kilogram-force (kgf)	newton (N)	9.80665
kilogram-force meter (kgf-m)	newton meter (N-m)	9.80665
kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	9.80665×10^4
kilogram-force per square centimeter (kgf/cm^2)	kilopascal (kPa)	9.80665×10^1
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	9.80665
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	9.80665×10^6
kilogram-force per square millimeter (kgf/mm^2)	megapascal (MPa)	9.80665
kilogram-force second square per meter ($kgf\text{-}s^2/m$)	kilogram (kg)	9.80665
light year (l.y.)	meter (m)	9.46073×10^{15}
liter (L)	cubic meter (m^3)	1.0×10^{-3}
microinch	meter (m)	2.54×10^{-8}
microinch	micrometer (μm)	2.54×10^{-2}
micron (μ)	meter (m)	1.0×10^{-6}
micron (μ)	micrometer (μm)	1.0
mil (0.001 in)	meter (m)	2.54×10^{-5}
mil (0.001 in)	millimeter (mm)	2.54×10^{-2}

(*Continued*)