CHAPTER 1

MATHEMATICAL AND PHYSICAL UNITS, STANDARDS, AND TABLES*

Jack H. Westbrook
Ballston Spa, New York

*This chapter is a revision and extension of Sections 1 and 3 of the third edition, which were written by Mott Souders and Ernst Weber, respectively. Section 4.4 is derived principally from ASTM's *Standard for Metric Practice*, ASTM E380-82, Philadelphia, 1982 (with permission). Section 6.1 is derived from *MIS Newsletter*, General Electric Co., 1980 (with permission).

1 SYMBOLS AND ABBREVIATIONS

Table 1 Greek Alphabet

A	α	Alpha	H	η	Eta	N	ν	Nu	T	τ	Tau
B	β	Beta	Θ	ϑ θ	Theta	Ξ	ξ	Xi	Υ	υ	Upsilon
Γ	γ	Gamma	I	ι	Iota	O	o	Omicron	Φ	ϕ	Phi
Δ	δ	Delta	K	κ	Kappa	Π	π	Pi	X	χ	Chi
E	ε	Epsilon	Λ	λ	Lambda	P	ρ	Rho	Ψ	ψ	Psi
Z	ζ	Zeta	M	μ	Mu	Σ	σ ς	Sigma	Ω	ω	Omega

Table 2 Symbols for Mathematical Operations[a]

Addition and Subtraction

$a + b$, a plus b
$a - b$, a minus b
$a \pm b$, a plus or minus b
$a \mp b$, a minus or plus b

Multiplication and Division

$a \times b$, or $a \cdot b$, or ab, a times b
$a \div b$, or $\frac{a}{b}$, or a/b, a divided by b

Symbols of Aggregation

() parentheses
[] brackets
{ } braces

–vinculum

Equalities and Inequalities

$a = b$, a equals b
$a \approx b$, a approximately equals b
$a \neq b$, a is not equal to b
$a > b$, a is greater than b
$a < b$, a is less than b
$a \gg b$, a much larger than b
$a \ll b$, a much smaller than b
$a \geqq b$, a equals or is greater than b
$a \leqq b$, a is less than or equals b
$a \equiv b$, a is identical to b
$a \to b$, or $a = b$, a approaches b as a limit

Proportion

$a/b = c/d$, or $a : b :: c : d$, a is to b as c is to d
$a \propto b$, $a \sim b$, a varies directly as b
%, percent

Powers and Roots

a^2, a squared
a^n, a raised to the nth power
$\sqrt{a}$, square root of a
$\sqrt[3]{a}$, cube root of a
$\sqrt[n]{a}$, or $a^{1/n}$, nth root of a

(*Continues*)

Table 2 (*Continued*)

a^{-n}, $1/a^n$
$3.14 \times 10^4 = 31{,}400$
$3.14 \times 10^{-4} = 0.000314$

Miscellaneous

$\overline{a}$, mean value of a
$a!, = 1 \cdot 2 \cdot 3 \ldots a$, factorial a
$|a|$ = absolute value of a
$P(n, r) = n(n-1)(n-2)\cdots(n-r+1)$
$C(n, r) = \dfrac{P(n, r)}{r!} = \dbinom{n}{r}$ = binomial coefficients
i (or j) $= \sqrt{-1}$, imaginary unit
$\pi = 3.1416$, ratio of the circumference to the diameter of a circle
∞, infinity

Plane Geometry

$<$, angle
Δ, triangle
$\|$, parallel
$\perp$, perpendicular
$\odot$, circle
$\square$, parallelogram
$\therefore$, therefore
$^\circ\ '\ ''$, degree, minute, second
$'\ ''$, feet, inches

Logarithms and Exponentials

$\log a = \log_{10} a$, common logarithm of a or log of a to the base 10
$\ln a = \log_e a$, natural logarithm of a or log of a to the base e ($e = 2.718$)
$\log^{-1} a$, number whose log is a
lb x or $\log_2 x$ = binary logarithm of x exponential of x, $\exp x$, e^x

Trigonometry

$\left.\begin{array}{l}\sin, \cos, \tan \\ \text{cosec or csc, sec, cot or ctn} \\ \text{vers, covers}\end{array}\right\}$ trigonometric functions

$\left.\begin{array}{l}\sin^{-1}, \cos^{-1}, \text{etc.} \\ \text{arcsin, arccos}\end{array}\right\}$ inverse of the functions

Analytic Geometry

$x, y, z; \xi, \eta, \zeta$, rectangular coordinates
ρ, s, intrinsic coordinates
ρ, radius of curvature
s, length of arc
r, θ, polar coordinates
ψ, angle from radius vector to tangent
r, θ, ϕ, spherical coordinates
θ, colatitude
ϕ, longitude
r, θ, z, cylindrical coordinates
e, eccentricity in conics
p, semi latus rectum in conics
$l = \cos\alpha, m = \cos\beta, n = \cos\gamma$, direction cosines

Calculus

$y = f(x), y$ is a function of x
$y' = f'(x) = \dfrac{dy}{dx} = D_x y$, derivative of $y = f(x)$ with respect to x
$y'' = f''(x) = \dfrac{d(y')}{dx} = D_x^2 y = \dfrac{d^2y}{dx^2}$, second derivative of $y = f(x)$ with respect to x
$u = f(x, y), u$ is a function of x and y
$u_x = f_x(x, y) = D_x(u) = \dfrac{\partial u}{\partial x}$, partial derivative of $u = f(x, y)$ with respect to x
$u_{xy} = f_{xy}(x, y) = D_y(D_x u) = \dfrac{\partial^2 u}{\partial y \partial x}$, second partial derivative of $u = f(x, y)$ with respect to x and y
Δy, increment of y
dy, differential of y
δy, variation of y
$\sum_{i=a}^{b}$, summation over i from a to b
$\lim_{x \to a}(y) = b, y \to b$ as $x \to a$
$\int$, integral of
$\int_a^b$, definite integral of

Vector Analysis

i, j, k, unit vectors along the axes (right-handed system)
$a \cdot b = (ab) = Sab$, scalar product of a and b
$a \times b = [ab] = Vab$, vector product of a and b
Vectors are indicated in print by boldfaced type.
$|A|, A$, absolute value
$\partial/\partial r, \nabla$, differential vector operator
grad $\varphi, \nabla\varphi$, gradient
div $A, \nabla \cdot A$, divergence
curl A, rot $A, \nabla \times A$, curl
$\Delta\varphi, \nabla^2\varphi$, Laplacian
$\square\varphi, \square^2 = \dfrac{1}{c^2}\dfrac{\partial^2}{\partial t^2} - \nabla^2$, D'Alembertian

Logic and Boolean Algebra

$a \in A, a$ is contained in set A
$A \cap B,\ A \cdot B$, logical multiplication. Intersection of set A and set B, A AND B
$A \cup B,\ A + B$, logical addition. Union of set A and set B. A OR B
$A \oplus B$, exclusive OR
$A \supset B$, logical inclusion. Inclusion of set B in set A
$A \ominus B$, complement of set B in set A
$\tilde{A}, \overline{A}$, logical complementation. NOT set A. Negation
$\emptyset$, 0, logical impossibility. Empty (null) set. Zero state
I, 1, logical certainty. Universal set. One state

[a] References: Mathematic signs and symbols for use in the physical sciences and technology, ANSI Y10.20 — 1975.

Table 3 Abbreviations[a] for Scientific and Engineering Terms[b]

Name of Term	Abbreviation
absolute	abs
acre	spell out
acre-foot	acre-ft
air horsepower	air hp
alternating-current (as adjective)	a-c
ampere	amp or A
ampere-hour	amp-hr
amplitude, an elliptic function	am.
Angstrom unit	A
antilogarithm	antilog
atmosphere	atm
atomic weight	at. wt.
average	avg
avoirdupois	avdp
azimuth	az or α
barometer	bar.
barrel	bbl
Baumé	Bé
board feet (feet board measure)	fbm
boiler pressure	spell out
boiling point	bp
brake horsepower	bhp
brake horsepower-hour	bhp-hr
Brinell hardness number	Bhn
British thermal unit[c]	Btu or B
bushel	bu
calorie	cal
candle	c
candle-hour	c-hr
candlepower	cp
cent	c or ¢
center to center	c to ¢
centigram	cg
centiliter	cl
centimeter	cm
centimeter-gram-second (system)	cgs
chemical	chem
chemically pure	cp
circular	cir
circular mils	cir mils
coefficient	coef
cologarithm	colog
concentrate	conc
conductivity	cond
constant	const
continental horsepower	cont hp
cord	cd
cosecant	csc
cosine	cos
cosine of the amplitude, an elliptic function	cn
cost, insurance, and freight	cif
cotangent	cot
coulomb	spell out or C
counter electromotive force	cemf
cubic	cu
cubic centimeter	cu cm, cm^3 (liquid, meaning milliliter, ml)
cubic foot	cu ft
cubic feet per minute	cfm
cubic feet per second	cfs
cubic inch	cu in.
cubic meter	cu m or m^3
cubic micron	cu μ or μ^3 or cu mu
cubic millimeter	cu *mm* or mm^3
cubic yard	cu yd
current density	spell out
cycles per second	spell out or cps or Hz
cylinder	cyl
day	spell out
decibel	db
degree[d]	deg or °
degree centigrade	C
degree Fahrenheit	F
degree Kelvin	K
degree Rankine	R
delta amplitude, an elliptic function	dn
diameter	diam
direct-current (as adjective)	d-c
dollar	$
dozen	doz
dram	dr
efficiency	eff
electric	elec
electromotive force	emf
elevation	el
equation	eq
external	ext
farad	spell out or F
feet board measure (board feet)	fbm
feet per minute	fpm
feet per second	fps
fluid	fl
foot	ft
foot-candle	ft-c
foot-Lambert	ft-L
foot-pound	ft-lb
foot-pound-second (system)	fps
foot-second (see cubic feet per second)	
franc	fr
free aboard ship	spell out
free alongside ship	spell out
free on board	fob
freezing point	fp
frequency	spell out
fusion point	fnp

(*Continues*)

Table 3 (*Continued*)

Name of Term	Abbreviation
gallons per minute	gpm
gallons per second	gps
grain	spell out
gram	g
gram-calorie	g-cal
greatest common divisor	gcd
haversine	hav
hectare	ha
henry	H
high-pressure (adjective)	h-p
hogshead	hhd
horsepower	hp
horsepower-hour	hp-hr
hour	hr
hour (in astronomical tables)	h
hundred	C
hundredweight (112 lb)	cwt
hyperbolic cosine	cosh
hyperbolic sine	sinh
hyperbolic tangent	tanh
inch	in.
inch-pound	in. lb
inches per second	ips
indicated horsepower	ihp
indicated horsepower-hour	ihp-hr
inside diameter	ID
intermediate-pressure (adjective)	i-p
internal	int
joule	J
kilocalorie	kcal
kilocycles per second	kcps
kilogram	kg
kilogram-calorie	kg-cal
kilogram-meter	kg-m
kilograms per cubic meter	kg per cu m or kg/m^3
kilograms per second	kgps
kiloliter	kl
kilometer	km
kilometers per second	kmps
kilovolt	kv
kilovolt-ampere	kva
kilowatt	kw
kilowatthour	kwhr
lambert	L
latitude	lat or ϕ
least common multiple	lcm
linear foot	lin ft
liquid	liq
lira	spell out
liter	L
logarithm (common)	log
logarithm (natural)	$\log_e$ or ln
longitude	long. or λ
low-pressure (as adjective)	l-p
lumen	lm
lumen-hour	lm-hr
lumens per watt	lpw
mass	spell out
mathematics (ical)	math
maximum	max
mean effective pressure	mep
mean horizontal candlepower	mhcp
megacycle	spell out
megohm	spell out
melting point	mp
meter	m
meter-kilogram	m-kg
mho	spell out
microampere	μ a or mu a
microfarad	μF
microinch	μ in.
micromicron	μμ or mu mu
micron	μ or mu
microvolt	μ v
microwatt	μ w or mu w
mile	spell out
miles per hour	mph
miles per hour per second	mphps
milliampere	ma
milligram	mg
millihenry	mH
millilambert	mL
milliliter	ml
millimeter	mm
millimicron	m μ or m mu
million	spell out
million gallons per day	mgd
millivolt	mV
minimum	min
minute	min
minute (angular measure)	
minute (time) (in astronomical tables)	m
mole	spell out
molecular weight	mol. wt
month	spell out
National Electrical Code	NEC
ohm	spell out or Ω
ohm-centimeter	ohm-cm
ounce	oz
ounce-foot	oz-ft
ounce-inch	oz-in.
outside diameter	OD
parts per million	ppm
peck	pk
penny (pence)	d
pennyweight	dwt

Table 3 (*Continued*)

Name of Term	Abbreviation
per	(see Fundamental Rules)
peso	spell out
pint	pt
potential	spell out
potential difference	spell out
pound	lb
pound-foot	lb-ft
pound-inch	lb-in.
pound sterling	£
pounds per brake horsepower-hour	lb per bhp-hr
pounds per cubic foot	lb per cu ft
pounds per square foot	psf
pounds per square inch	psi
pounds per square inch absolute	psia
power factor	spell out or pf
quart	qt
radian	spell out
reactive kilovolt-ampere	kvar
reactive volt-ampere	var
revolutions per minute	rpm
revolutions per second	rps
rod	spell out
root mean square	rms
secant	sec
second	sec
second (angular measure)	″
second-foot (see cubic feet per second)	
second (time) (in astronomical tables)	s
shaft horsepower	shp
shilling	s
sine	sin
sine of the amplitude, an elliptic function	sn
specific gravity	sp gr
specific heat	sp ht
spherical candle power	scp
square	sq
square centimeter	sq cm or cm^2
square foot	sq ft
square inch	sq in.
square kilometer	sq km or km^2
square meter	sq m or m^2
square micron	sq μ or sq mu or μ^2
square millimeter	sq mm or mm^2
square root of mean square	rms
standard	std
steradian	sr
tangent	tan
temperature	temp
tensile strength	ts
thousand	M
thousand foot-pounds	kip-ft
thousand pound	kip
ton	spell out
ton-mile	spell out
versed sine	vers
volt	V
volt-ampere	Va
volt-coulomb	spell out
watt	W
watthour	Whr
watts per candle	Wpc
week	spell out
weight	wt
yard	yd
year	yr

[a]These forms are recommended for readers whose familiarity with the terms used makes possible a maximum of abbreviations. For other classes of readers, editors may wish to use less contracted combinations made up from this list. For example, the list gives the abbreviation of the term "feet per second" "fps." To some readers ft/sec will be more easily understood.

[b]This list of abbreviations is adapted from the recommendations of the American National Standards Institute [see ANSI Y1.1-1972 (R1984)].

[c]Abbreviation recommended by the American Society of Mechanical Engineers (ASME) Power Test Codes Committee. B = 1 Btu, kB = 1000 Btu, mB = 1,000,000 Btu. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) recommends the use of Mb = 1000 Btu and Mbh = 1000 Btu/hr.

[d]There are circumstances under which one or the other of these forms is preferred. In general the sign° is used where space conditions make it necessary, as in tabular matter, and when abbreviations are cumbersome, as in some angular measurements, i.e., 59°23′ 42″. In the interest of simplicity and clarity the Committee has recommended that the abbreviation for the temperature scale, °F, °C, K, etc., always be included in expressions for numerical temperatures, but, wherever feasible, the abbreviation for "degree" be omitted; as 69 F.

Table 4 Symbols for Physical Quantities[a,b]

Name of Quantity	Symbol
Absorption factor	α
Acceleration	
Angular	α
Linear, general	a
Acceleration due to gravity	
General	g
International adopted standard	g_0
Local	g_L
Gravitational conversion factor	g_c
Activity	a
Activity coefficient, molal basis	γ
Adiabatic factor	X
Admittance	Y
Advanced ratio of propeller	J
Altitude	h, z
Amplitude	A
Angle	α
Angle	$\beta\ \phi$
Blade angle	β
Effective helix	ψ
Dihedral	Γ
Helical angle of advance	ϕ
Of attack	α
Of downwash	ε
Of radiation	θ
Of sideslip	β
Of sidewash	σ
Solid	ω
Angular	
Acceleration	α
Displacements	δ
Frequency	ω
Momentum	H
Velocity	ω
Area	A
Area[c]	S
Aspect ratio	A, AR
Atomic weight	A
Attack, angle of	α
Attenuation	a
Axes	
Of aircraft (left handed)	
Earth-bound coordinate system	x, y, z
Lateral	Y
Longitudinal	X
Normal	Z
Bazin's coefficient of roughness	m
Blade width (propellers)	b
Boundary layer thickness	δ
Breadth	b
Capacitance, capacity	C
Capacitivity	ε
Of evacuated space	ε_v
Relative	ε_r
Charge, electric or quantity of electricity	Q
Charge density	
Line density of charge	λ
Surface density of charge	σ
Volume density of charge	ρ
Chézy's coefficient	C
Chord length	c
Circular frequency ($2\pi f$)	ω
Circulation, strength of single vortex	Γ
Coefficient	
Absolute	C
General	C
Of contraction	C_c
Of discharge	C
Of discharge	C_q
Of energy per unit weight in $C_e(V^2/29)$	C_e
Of flow (Chézy)	C
Of friction (Weisbach–Darcy)	f
Of friction	μ, f
Of momentum per unit weight in $C_m(V/g)$	C_m
Of roughness (Bazin)	m
Of roughness (Kutter and Manning)	n
Of heat transfer overall	V
Of velocity	C_v
Compressibility factor	z
Concentrated load	F, P, Q
Concentration	C, c
Concentration, volumetric	c
Concentration factor, stress	K
Conductance	
Electrical	G
Thermal	$1/R$
Per unit area	$1/RA$
Conductivity	
Electrical	γ, σ
Equivalent	Λ
Thermal	k
Contraction, coefficient of	C_c
Correlation coefficient	R
Coupling coefficient	k
Critical state or indicating critical value (subscript)	c
Current[d]	I
Damping	
Coefficient	c
Constant or coefficient	δ
Factor	λ
Deflection	δ
Of beam, maximum	δ
Density	ρ
Relative to standard air density	σ
Depth	h
Depth	y
Of flow, channels	y
Diameter	D
Dielectric constant	ε
Difference between values	Δ
Difference of potential[d,e]	E, e
Diffusion coefficient	D_v
Diffusivity	α
Diffusivity, thermal	α
Of vapor	D_v
Discharge	
Coefficient of	C_q
Coefficient of	C
Rate of; or flow	Q

Table 4 (*Continued*)

Name of Quantity	Symbol
Per unit width	q
Displacement, electric	D
Distance	
From center of gravity to center of pressure of horizontal tail surface	f
Linear	s
Drag, absolute coefficient of	D
Dynamic (or impact) pressure	q
Eccentricity of application of load	e
Efficiency	η
Elastance	S
Mutual	S_m, S_{rc}
Self	S, S_{cc}
Elasticity	
Bulk modulus, of liquids	K
Kinematic K/ρ	e
Modulus of	E
Elastivity	σ
Electric potential[d,e]	E, e
Electricity, quantity of	Q, q
Electromotive force[d]	E, e
Electronic charge, absolute value	e
Electrostatic flux	ψ
Elevation	
Above datum	Z
Above stream bed	Z_0
Elongation, total	δ
Emissivity, total	ε
Energy	W
Work total	E
Energy	E
Internal; intrinsic[f]	U, u
Kinetic	E_k, T
Per unit time (power)	P
Potential	E_p, V
Enthalpy[f]	H or h
Enthalpy	H
Of dry saturated vapor	h_g
Of saturated liquid	h_f
Per unit weight	h
Entropy	S, s
Error signal	ε
Expansion, exponent of polytropic	n
Cubical, thermal coefficient	β
Linear, thermal coefficient	α
Factor of safety	N
Film thickness, effective	B
Flow rate	w
In pounds per unit of time	w
Volumetric	q
Fluidity	$1/\mu$
Flux	
Density, magnetic	B
Displacement	ψ
Magnetic	Φ
Force	F
Force	F
Electromotive[e]	E, e
Magnetomotive	$M, \mathscr{F}$
Moment of	M
Normal	N
Shearing force in beam section	V
Total load	F
Forces or loads, concentrated	P, Q, F
Fraction	
By volume	x_v
By weight	x_w
Free energy	
Gibbs	G
Helmholtz	A
Frequency	f
Circular ($2\pi f$)	θ
Of radiant energy	ν
Reduced (flutter)	k
Rotational	n
Frequency, angular	ω
Friction	
Coefficient of sliding	f, μ
Factor used in expressing pipeloss	f
In energy balance	F
Fugacity	f
Gas constant	R
Gibbs function, total potential function	G, g
Gyration, radius of	k
Head	
Atmospheric	h_a
Lost[c]	h
Potential	h_{pz}
Pressure	h_p
Velocity	h_v
Heat	
Content; enthalpy[f]	H, h
Content of dry saturated vapor; enthalpy of dry saturated vapor	h_g
Content of saturated liquid; enthalpy of saturated liquid	h_f
Equivalent of work	$1/J$
Flow rate	q
Across a boundary surface	h
Latent, of evaporation	λ, h_{fg}
Mechanical equivalent of	J
Of vaporization at constant pressure[f]	H_{fg}, λ, or h_{fg}
Specific, at constant pressure	c_p
Specific, at constant volume	c_v
Ratio of specific heats	γ, κ, or k
Transfer, overall coefficient of	U
Transfer, surface coefficient of	h
Height	h
Crest, weirs	z
Helix, effective angle	Φ

(*Continues*)

Table 4 (*Continued*)

Name of Quantity	Symbol
Helmholtz free energy; internal potential function[f]	A, a
Humidity	H
Density of water vapor; weight of water vapor per unit of volume of space	ρ_H
Density of water vapor at saturation	ρ_s
Enthalpy of the mixture minus the enthalpy of the liquid at the temperature of adiabatic saturation; carrier sigma function	h_Σ
Humid volume, volume of mixture per unit of weight of dry air	v_H
Partial pressure of water vapor	p_H
Percentage humidity by weight	w_H/w_s
Relative humidity; ratio of an actual partial pressure of water vapor in air to the saturation partial pressure	H_R
Saturation pressure of water vapor	p_s
Saturation weight of water vapor per unit of weight of air	H_s, w_s
Weight of water vapor per unit of weight of dry air	H, w_H
Hydraulic radius	R_H
Mean in a reach	R_m
Of cross-sectional area	R
Hydraulic slope	S_w
Impedance	Z
Impulse	I
Inductance	L
Magnetic	B
Mutual	L_m
Self	L, L_{cc}
Inertia, moment of	I
Inertia, moment of	
Polar	J
Rectangular	I
Product moment of	I_{xy}
Intensity	
Electric	$\mathbf{E}$, $\mathbf{K}$
Magnetic	$\mathbf{H}$
Isentropic factor	X
Joule–Thomson coefficient	μ
Kutter coefficient of roughness	n
Length	L
Length	l
Lift	L
Linear expansion, coefficient	α
Linear velocity	v
Load	
Concentrated	F, P, Q
Eccentricity of application of	e
Factor	n
Per unit distance	w, q
Total	W, P
Mach	
Angle	μ
Number	M
Magnetic	
Flux	Φ
Intensity	$\mathbf{H}$
Magnetomotive force	$M, \mathscr{F}$
Mass	m
Flow rate	w
Velocity	G
Mean free path	λ
Mechanical equivalent of heat	J
Microscale (turbulence)	λ
Modulus	
Bulk, of elasticity of liquids	K
Of elasticity	E
Of elasticity in shear	G
Section	Z
Shear	G
Molecular weight	M
Moment	
Electric	$\mathbf{p}$
Magnetic	$\mathbf{m}$
Of any area about a given axis, statical	Q
Of force, including bending moment	M
Of inertia, polar	J
Rectangular	I
Mutual inductance	L_m
Neutral axis, distance to extreme fiber	c
Nozzle divergence factor	λ
Number in general	N
Of conductors or turns	N
Of moles, pound-moles, kilogram-moles, etc.	n
Of phases	m
Of poles	p
Of revolutions per unit of time	n
Perimeter, wetted, of a sectional area	P
Period	T
Permeability	
Magnetic	μ
Of evacuated space	μ_c
Relative	μ_r
Permeance	$\mathscr{P}, \Lambda$
Permittivity	ε
Phase	
Angle	ϕ
Constant	β
Displacement	ϕ
Pitch, geometric	p
Planck constant	h
Poisson ratio	μ, ν
Polarization, magnetic	B_i
Pole strength	m

Table 4 (*Continued*)

Name of Quantity	Symbol
Potential	
Electric[d,e]	V
Function	ϕ
Function, internal; Helmholtz free energy	A, a
Function, total; Gibbs function	G, g
Magnetic	$\mathbf{M}$, $\mathscr{F}$
Magnetic vector	$\mathbf{A}$
Retarded vector	$\mathbf{A}_r$
Power	
Active	P
Apparent	S
Factor	F_p
Reactive	Q
Pressure	
Dynamic	q
Intensity; force per unit area	p
Relative	δ
Saturation of water vapor	p_s
Propagation constant	γ
Poynting vector	Π
Q factor of a reactor	Q
Quality of vapor	x
Quantity	
Of electricity	Q
Of heat per unit mass or unit weight	q
Of heat per unit time	q
Of matter	W
Total, of a fluid, water, gas, heat (by volume)	Q
Radiant density	u
Radiant energy	U
Radiant flux	Φ
Density	W
Radiant intensity	J
Radiation, intensity of	N
Radii	r, R
Radius	r
Of gyration	k
Range	R
Reactance	X
Capacitive	X_c
Inductive	X_L
Mutual	X_m, X_{rc}
Self	X, X_{cc}
Reactive factor	F_q
Recovery factor	η_r
Reduced frequency (flutter)	k
Reflection factor	ρ
Reluctance	$\mathscr{R}$
Reluctivity	ν
Resistance	
Electrical	R
Temperature coefficient	α
Thermal	R
Per unit area	RA
Resistivity	
Electrical	ρ
Thermal	$1/k$
Revolutions per unit time	n
Reynolds number	R
Richness; equivalence ratio (combustion)	R
Rotation	
Rate of	n
Speed of	n
Safety factor	N
Saturation pressure of water vapor	p_s
Section modulus	Z
Self-inductance	L, L_{cc}
Set of control surfaces, angle of[c]	δ
Shape factor	S
Shearing force in beam section	V
Slip	s
Slope	
Of channel bed	S_0
Of cuts and embankments	s
Of energy grade line	S
Of hydraulic grade line	S_w
Of lift curve	a
Solidity, propellers	σ
Span	b
Effectiveness	e
Specific	
Gravity	G
Heat	c
Heat at constant pressure	c_p
Molar	C_p
Heat at constant volume	c_v
Molar	C_v
Heats, ratio	γ or k or k
Volume	v
Weight	γ
Speed	
Linear	V, v, u
Of rotation	n
Spring constant	k
Stefan–Boltzmann constant	σ
Strain	
Normal	ε
Shear	γ
Stream function	ψ
Stress	
Concentration factor	K
Normal	σ, s
Shear	τ, s_s
Supercompressibility factor	z
Surface coefficient of heat transfer	h
Surface per unit volume	a
Surface tension	σ
Kinematic σ/ρ	ω
Susceptance	B
Susceptibility	
Dielectric	η
Magnetic	κ
Sweepback angle	Λ
Taper ratio	λ
Temperature	
Absolute[g] (°F abs or K)	T or Θ
Ordinary[g] (°F or °C)	t or θ

(*Continues*)

Table 4 (*Continued*)

Name of Quantity	Symbol
Ratio	θ
Thermal	
Conductance	$1/R$
Per unit area; "unit conductance"	$1/RA$
Conductivity	k
Diffusivity	α
Resistance	R
Resistance of unit area	RA
Resistivity	$1/k$
Transfer factor	j
Transmission	q
Thickness	d, t, or h
Thrust	
Stream	F
Propeller	T
Time	t
Time[h]	t or τ
Time constant	τ
Torque	Q
Torque	T or M
Transmission	
Factor	τ
Thermal	q
Turbulence exchange, coefficient	ε
Turbulence scale	L
Vaporization, heat of, at constant pressure	H_{fg}, h_{fg}, λ
Velocity	V
Velocity	V or v
Acoustic	V_a
Angular	ω
Average	V
Belanger critical	V_c
Components in x, y, z directions, respectively	u, v, w
Linear	v
Local	u
Mass, mass flow, per unit cross-sectional area, per unit time	G
Mean (Q/A)	V
Of light	c
Of sound	a, c
Of uniform flow	V_0
Of wave celerity	c
Relative	v
Temporal means of components	$\overline{u}, \overline{v}, \overline{w}$
Vibration constant	p
Viscosity	
Absolute; coefficient of	μ
Kinematic	ν
Relative (to absolute viscosity of water)	μ/μ_w
Relative kinematic	use ν/ν_w
Voltage[d]	E, e
Volume	V
Molar	V, V_m
Specific	v
Total	V, V_L
Volume rate; discharge by volume, fluid rate of flow by volume	q, Q
Wavelength	λ
Constant	β
Weight	
Molecular	M
Per unit time per unit area of cross section; "mass velocity"	G
Per unit volume	γ
Rate; per unit of power; for unit of time	w
Rate of flow per unit of breadth	Γ
Specific, with g_c	γ
Total	W
Weirs	
Crest height	z
Crest length	b
Degree of submergence	N
Wetted perimeter	L_p
Width (same as breadth)	b
Of stream bed	b
Width, channel surface	b_w
Wing setting, angle of (angle between the wing chord and the thrust line)	i_w
Work	W
External	W_e
Heat equivalent of	$1/J$ or A
Per unit weight	w, w_k

[a]The most frequently used American Standard and Tentative Standard Symbols are included in this table. Sources used are publications of the American National Standards Institute shown in the bibliography below.
[b]Where possible, capital letters denote total quantities and small letters denote specific quantities, or quantities per unit.
[c]Use with appropriate subscript.
[d]Where distinctions between maximum, instantaneous, effective (root-mean-square), and average values are necessary, E_m, I_m, P_m are recommended for maximum values; e, i, p for instantaneous values; E, I for effective (rms) values; and P for average value.
[e]Where a distinction between electromotive force and difference of electric potential is desirable, the symbols E, e, and V, v, respectively, may be used.
[f]In each instance uppercase italics may be used optionally for values in general or per mole. Molal values may have subscript M. Lowercase italics are to be used for specific values (per pound, gram, liter, etc.). Molecular values may be represented by lowercase italics or by lowercase italics with subscript m.
[g]θ is preferable only when t is used for time in the same discussion. Θ is preferable only when θ is used for ordinary temperature.
[h]τ should be used only when t is used for ordinary temperature in the same discussion.

BIBLIOGRAPHY FOR LETTER SYMBOLS

Acoustics, Letter Symbols and Abbreviations for Quantities Used in, ANSI/ASME Y10.11-1984.

Aeronautical Sciences, Letter Symbols for, ANSI Y10.7-1954.

Chemical Engineering, Letter Symbols for, ANSI Y10.12-1955(R1973).

Glossary of Terms Concerning Letter Symbols, ANSI Y10.1-1972.

Heat and Thermodynamics, Letter Symbols for, ANSI Y10.4-1982.

Hydraulics, Letter Symbols for, ANSI Y10.2-1958.

Illuminating Engineering, Letter Symbols for, ANSI Y10.18-1967(R1977).

Letter Symbols for SI Units and Certain Other Units of Measurement, ANSI/IEEE 260-1978.

Mathematic signs and Symbols for Use in Physical Sciences and Technology (includes supplement ANSI Y10.20a-1975), ANSI Y10.20-1975.

Mechanics and Time-Related Phenomena, ANSI/ASME Y10.3M-1984.

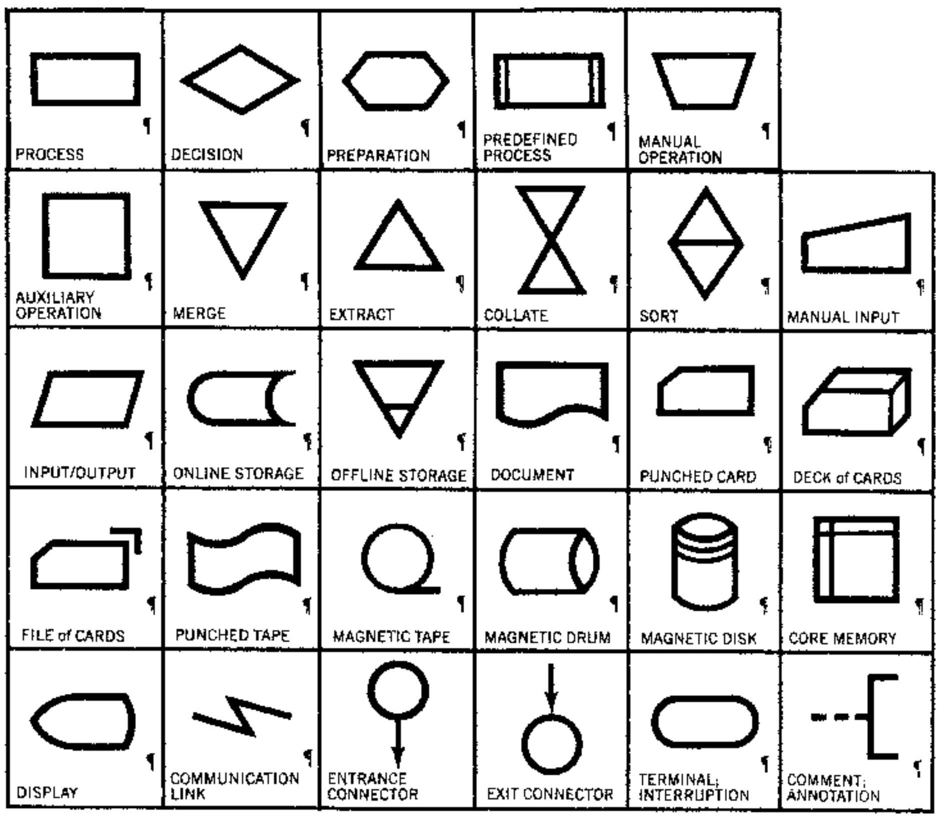
Meteorology, Letter Symbols for, ANSI Y10.10-1953(R1973).

Quantities Used in Electrical Science and Electrical Engineering, Letter Symbols for, ANSI/IEEE 280-1985.

Selecting Greek Letters Used as Letter Symbols for Engineering Mathematics, Guide for, ANSI Y10.17-1961 (R1973).

Table 5 Graphic Symbols (after Dreyfus, 1972)

Symbols are a graphical referrent to information and have been used for millennia as devices for convenient shorthand notation, to restrict interpretation only to *cognoscenti*, or for compression of data. Examples from several engineering fields are shown here. ISO recommendations are indicated by ¶ and ISO draft recommendations by ¶¶.



(*Continues*)

Table 5 (*Continued*)

Chemical Engineering

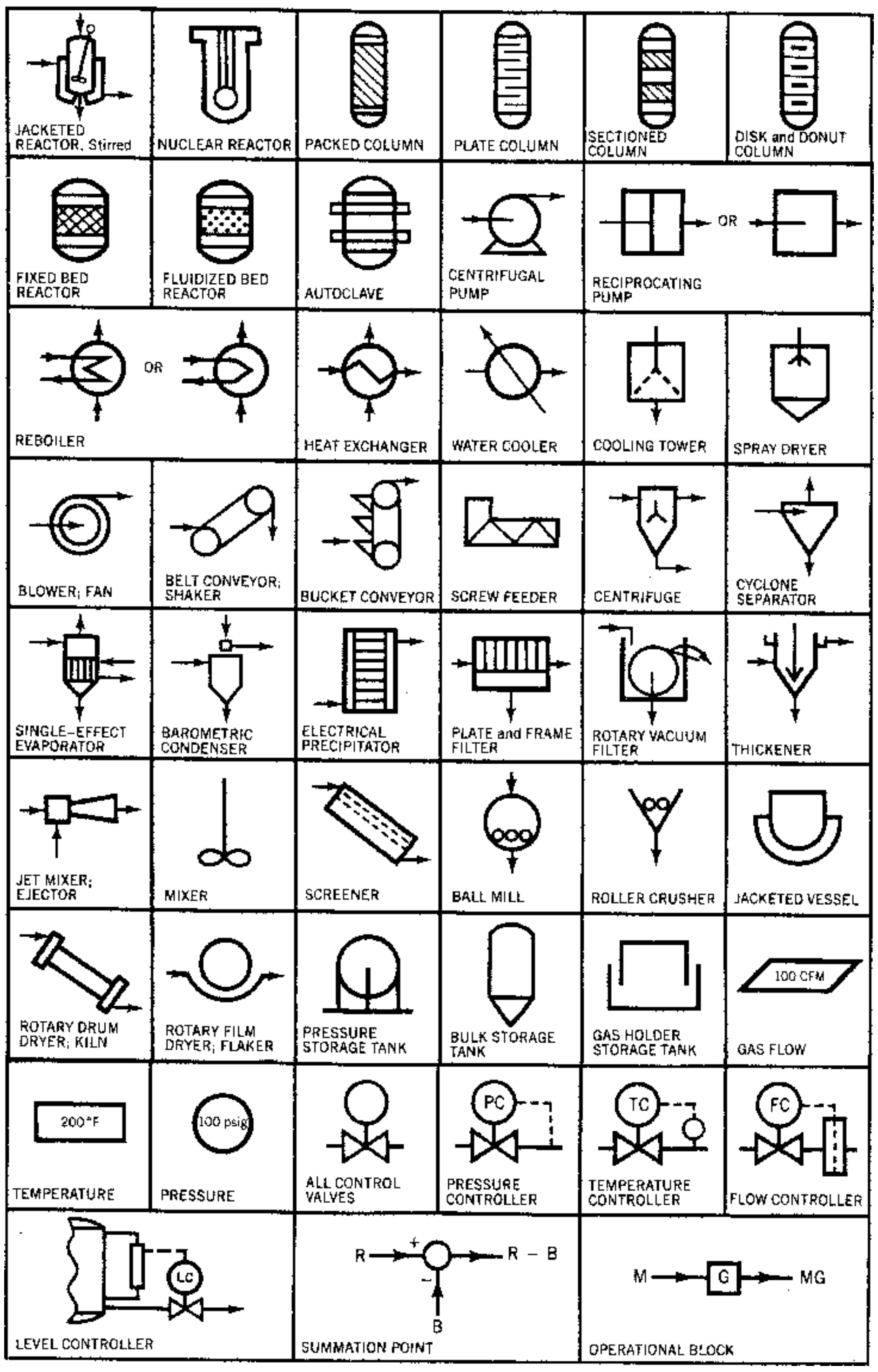
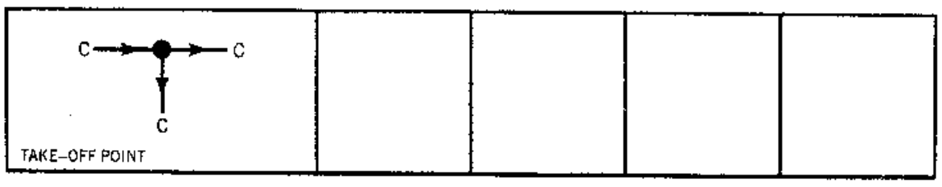
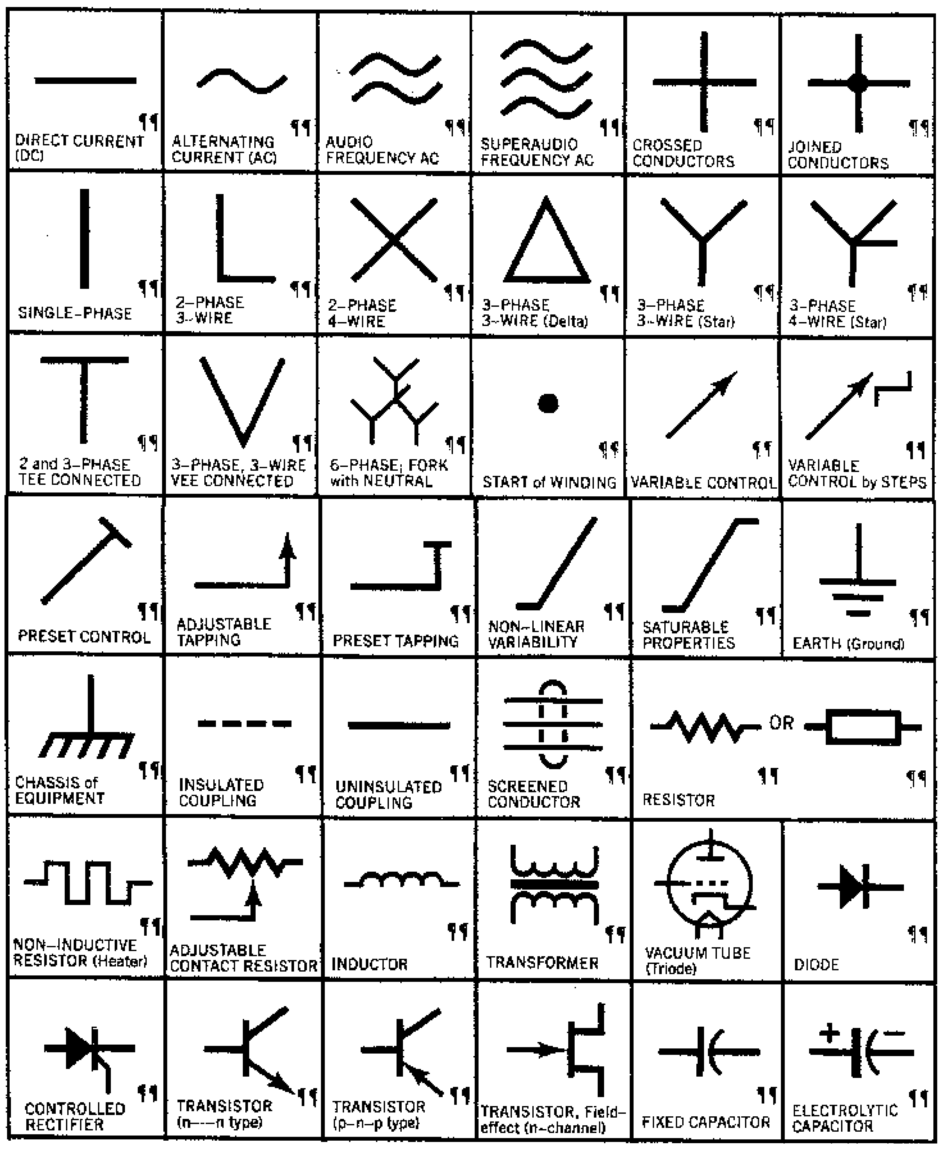


Table 5 (*Continued*)

Chemical Engineering (continued)



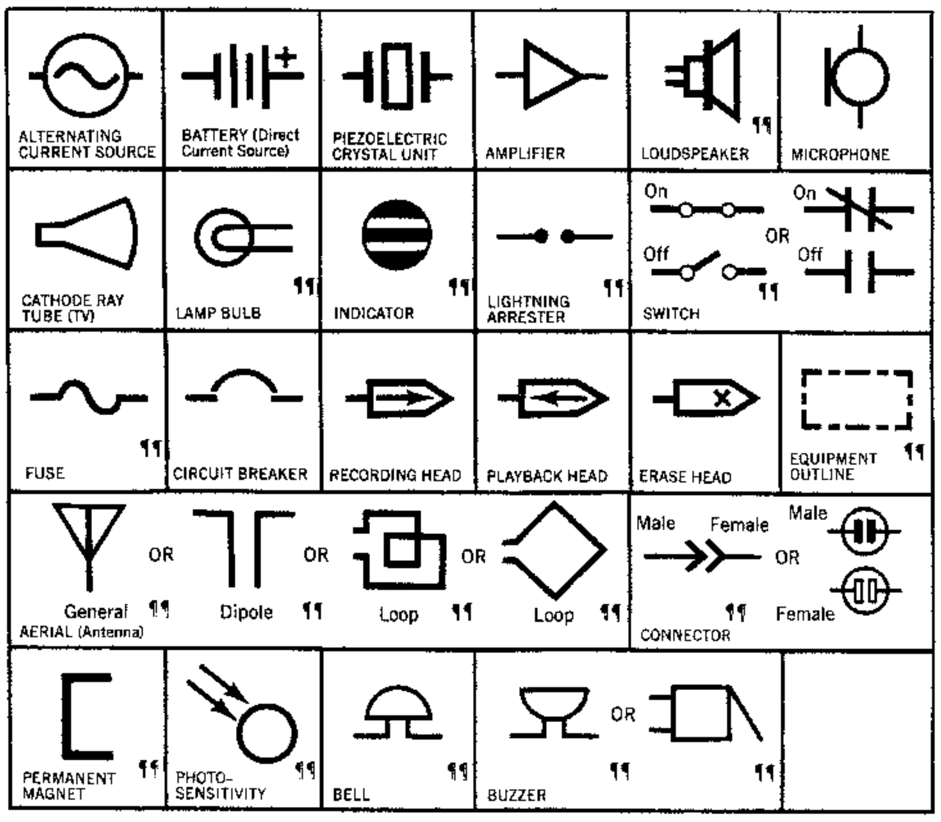
Electrical Engineering



(*Continues*)

Table 5 (*Continued*)

Electrical Engineering (continued)



¶¶ Draft ISO Recommendation

Mechanical Engineering

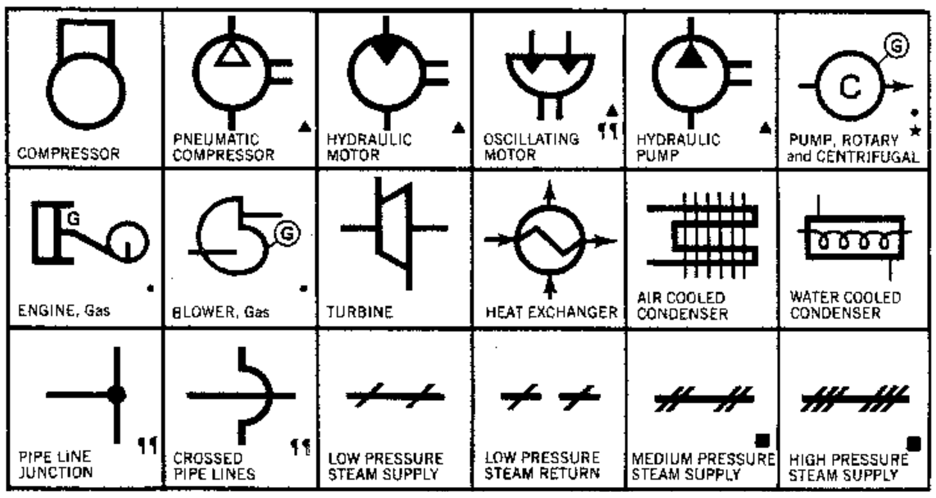
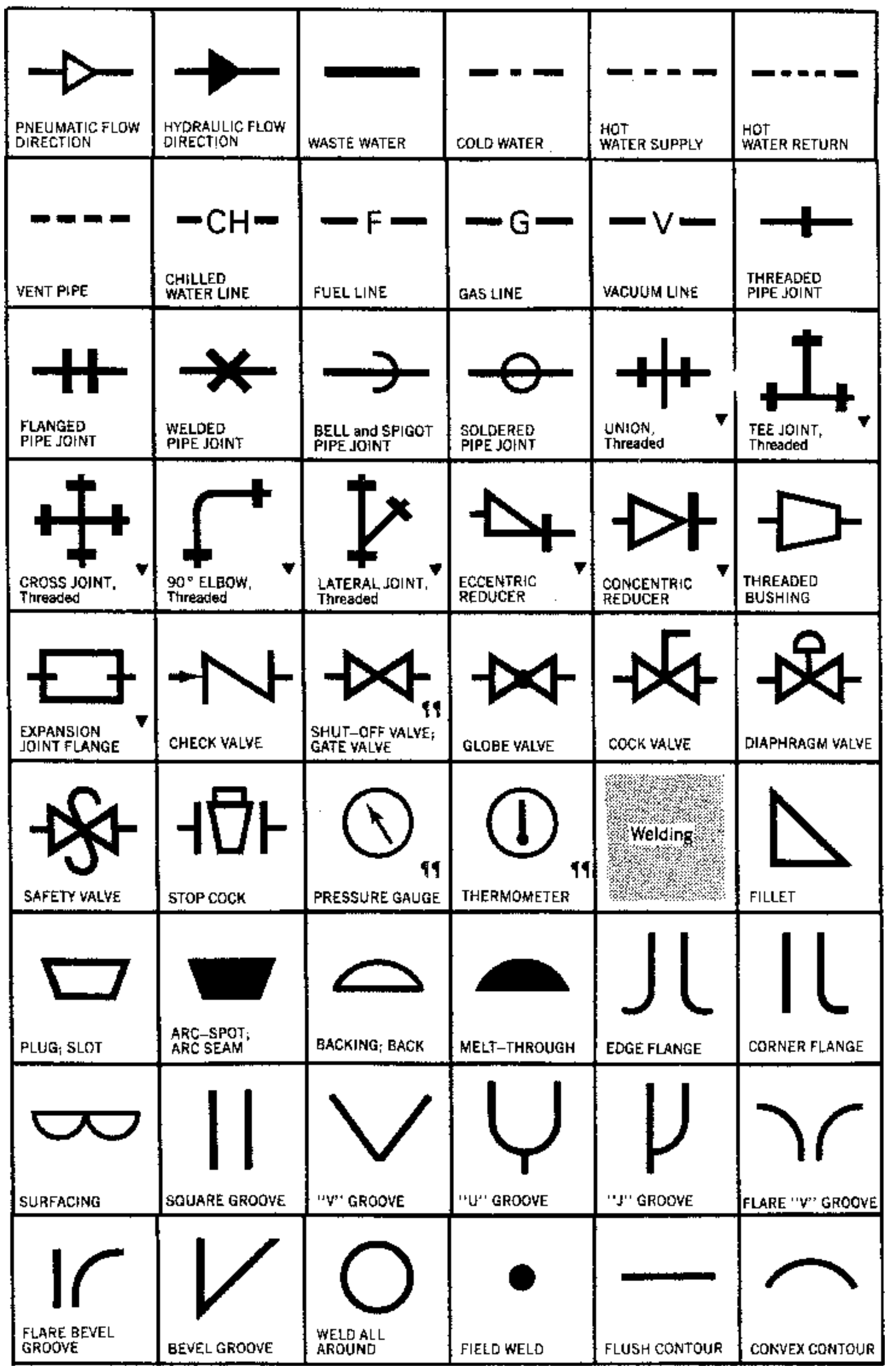


Table 5 (*Continued*)

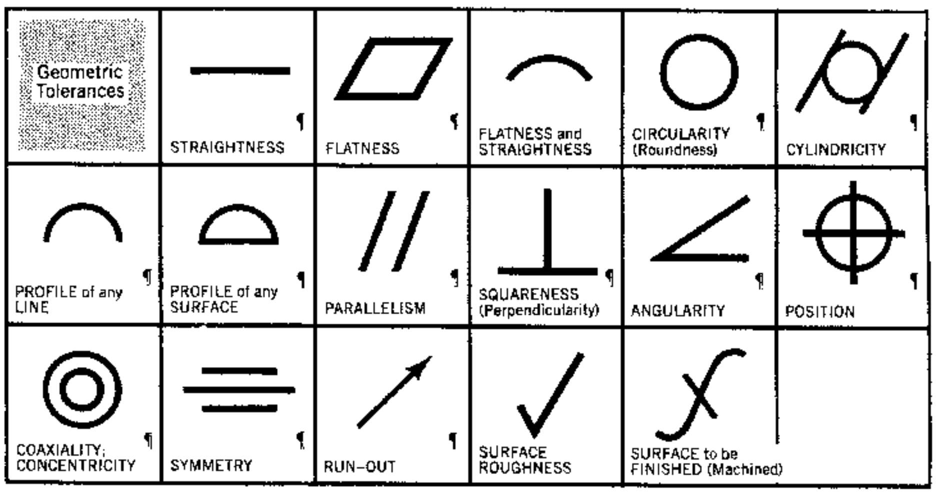
Mechanical Engineering (continued)



(*Continues*)

Table 5 (*Continued*)

Mechanical Engineering (continued)



▲ Pneumatic machinery is indicated by △, hydraulic machinery by ▲
• G indicates Gas. Different initial may be substituted to indicate other type of machine: e.g., D (diesel), M (motor), T (turbine), E (steam). Exception: (see Engine, Gas) Steam Engine is indicated by symbol without initial.
▲ C indicates Circulating Water. Different initial indicates other type of machine or service; e.g., D (concentrate), F (boiler feed), O (oil), S (service), V (air).
■ "Return" indicated by broken line, as illustrated in Low Pressure Steam Return.
¶¶ Draft ISO Recommendation
▼ Flanged, Welded, Bell and Spigot, or Soldered Union indicated by substituting appropriate markings (see Joints). Example: ✕|✕ Welded Union.
¶ ISO Recommendation

BIBLIOGRAPHY FOR GRAPHIC SYMBOLS

Arnell, A. *Standard Graphical Symbols—A Comprehensive Guide for Use in Industry, Engineering and Science*, McGraw-Hill, New York, 1963.

Dreyfus, H. *Symbol Sourcebook*, McGraw-Hill, New York, 1972.

Electrical and Electronics Diagrams (Including Reference Designation Class Designation Letters), Graphic Symbols for, ANSI/IEEE 315-1975.

Electrical and Electronics Diagrams, Graphic Symbols for (supplement to ANSI/IEEE 315-1975), ANSI/IEEE 315A-1986.

Electrical and Electronics Parts and Equipments, Reference Designations for, ANSI/IEEE 200-1975.

Electrical Wiring and Layout Diagrams Used in Architecture and Building Construction, Graphic Symbols for, ANSI Y32.9-1972.

Fire Fighting Operations, Symbols for, ANSI/NFPA 178-1980.

Fire Protection Symbols for risk Analysis Diagrams, ANSI/NFPA 174-1980.

Fire-Protection Symbols for Architectural and Engineering Drawings, ANSI/NFPA 172-1980.

Fluid Power Diagrams, Graphic Symbols for, ANSI Y32.10-1967(R1979).

Grid and Mapping Used in Cable Television Systems, Graphic Symbols for, ANSI/IEEE 623-1976.

Heat-Power Apparatus, Graphic Symbols for, ANSI Y32.2.6M-1984.

Heating, Ventilating, and Air Conditioning, Graphic Symbols for, ANSI Y32.2.4M-1984.

Polon, D. D. (Ed.), *Encyclopedia of Engineering Signs and Symbols*, Odyssey Press, New York, 1965.

Shepard, W., *Shepard's Glossary of Graphic Signs and Symbols*, Dent, London, 1971.

Table 6 Personal Computer Numeric Codes for Characters and Symbols

IBM PC Character Set (00–7F) Quick Reference

DECIMAL VALUE	→	0	16	32	48	64	80	96	112
↓	HEXA DECIMAL VALUE	0	1	2	3	4	5	6	7
0	0	BLANK (NULL)	►	BLANK (SPACE)	0	@	P	'	p
1	1	☺	◄	!	1	A	Q	a	q
2	2	☻	↕	"	2	B	R	b	r
3	3	♥	‼	#	3	C	S	c	s
4	4	♦	¶	$	4	D	T	d	t
5	5	♣	§	%	5	E	U	e	u
6	6	♠	▬	&	6	F	V	f	v
7	7	•	↨	'	7	G	W	g	w
8	8	◘	↑	(	8	H	X	h	x
9	9	○	↓	)	9	I	Y	i	y
10	A	◙	→	*	:	J	Z	j	z
11	B	♂	←	+	;	K	[	k	{
12	C	♀	∟	,	<	L	\	l	¦
13	D	♪	↔	—	=	M	]	m	}
14	E	♫	▲	.	>	N	^	n	~
15	F	☼	▼	/	?	O	_	o	Δ

IBM PC Character Set (80–FF) Quick Reference

DECIMAL VALUE	→	128	144	160	176	192	208	224	240
↓	HEXA DECIMAL VALUE	8	9	A	B	C	D	E	F
0	0	Ç	É	á	░	└	╨	α	≡
1	1	ü	æ	í	▒	┴	╤	β	±
2	2	é	Æ	ó	▓	┬	╥	Γ	≥
3	3	â	ô	ú	│	├	╙	π	≤
4	4	ä	ö	ñ	┤	─	╘	Σ	⌠
5	5	à	ò	Ñ	╡	┼	╒	σ	⌡
6	6	å	û	ª	╢	╞	╓	μ	÷
7	7	ç	ù	º	╖	╟	╫	τ	≈
8	8	ê	ÿ	¿	╕	╚	╪	Φ	°
9	9	ë	Ö	⌐	╣	╔	┘	Θ	●
10	A	è	Ü	¬	║	╩	┌	Ω	•
11	B	ï	¢	½	╗	╦	█	δ	√
12	C	î	£	¼	╝	╠	▄	∞	ⁿ
13	D	ì	¥	¡	╜	═	▌	φ	²
14	E	Ä	₧	«	╛	╬	▐	∈	■
15	F	Å	ƒ	»	┐	╧	▀	∩	BLANK 'FF'

Source: Reprint courtesy of International Business Machines Corporation, copyright 1985 © by International Business Machines Corporation.

Table 7 Conversions for Number Systems of Different Bases

Radix 16 Hexadecimal	Radix 10 Decimal	Radix 8 Octal	Radix 2 Binary		Radix 16 Hexadecimal	Radix 10 Decimal	Radix 8 Octal	Radix 2 Binary	
			BIT					BIT	
			8765	4321				8765	4321
00	0	00	0000	0000	3A	58	72	0011	1010
01	1	01	0000	0001	3B	59	73	0011	1011
02	2	02	0000	0010	3C	60	74	0011	1100
03	3	03	0000	0011	3D	61	75	0011	1101
04	4	04	0000	0100	3E	62	76	0011	1110
05	5	05	0000	0101	3F	63	77	0011	1111
06	6	06	0000	0110	40	64	100	0100	0000
07	7	07	0000	0111	41	65	101	0100	0001
08	8	10	0000	1000	42	66	102	0100	0010
09	9	11	0000	1001	43	67	103	0100	0011
0A	10	12	0000	1010	44	68	104	0100	0100
0B	11	13	0000	1011	45	69	105	0100	0101
0C	12	14	0000	1100	46	70	106	0100	0110
0D	13	15	0000	1101	47	71	107	0100	0111
0E	14	16	0000	1110	48	72	110	0100	1000
0F	15	17	0000	1111	49	73	111	0100	1001
10	16	20	0001	0000	4A	74	112	0100	1010
11	17	21	0001	0001	4B	75	113	0100	1011
12	18	22	0001	0010	4C	76	114	0100	1100
13	19	23	0001	0011	4D	77	115	0100	1101
14	20	24	0001	0100	4E	78	116	0100	1110
15	21	25	0001	0101	4F	79	117	0100	1111
16	22	26	0001	0110	50	80	120	0101	0000
17	23	27	0001	0111	51	81	121	0101	0001
18	24	30	0001	1000	52	82	122	0101	0010
19	25	31	0001	1001	53	83	123	0101	0011
1A	26	32	0001	1010	54	84	124	0101	0100
1B	27	33	0001	1011	55	85	125	0101	0101
1C	28	34	0001	1100	56	86	126	0101	0110
1D	29	35	0001	1101	57	87	127	0101	0111
1E	30	36	0001	1110	58	88	130	0101	1000
1F	31	37	0001	1111	59	89	131	0101	1001
20	32	40	0010	0000	5A	90	132	0101	1010
21	33	41	0010	0001	5B	91	133	0101	1011
22	34	42	0010	0010	5C	92	134	0101	1100
23	35	43	0010	0011	5D	93	135	0101	1101
24	36	44	0010	0100	5E	94	136	0101	1110
25	37	45	0010	0101	5F	95	137	0101	1111
26	38	46	0010	0110	60	96	140	0110	0000
27	39	47	0010	0111	61	97	141	0110	0001
28	40	50	0010	1000	62	98	142	0110	0010
29	41	51	0010	1001	63	99	143	0110	0011
2A	42	52	0010	1010	64	100	144	0110	0100
2B	43	53	0010	1011	65	101	145	0110	0101
2C	44	54	0010	1100	66	102	146	0110	0110
2D	45	55	0010	1101	67	103	147	0110	0111
2E	46	56	0010	1110	68	104	150	0110	1000
2F	47	57	0010	1111	69	105	151	0110	1001
30	48	60	0011	0000	6A	106	152	0110	1010
31	49	61	0011	0001	6B	107	153	0110	1011
32	50	62	0011	0010	6C	108	154	0110	1100
33	51	63	0011	0011	6D	109	155	0110	1101
34	52	64	0011	0100	6E	110	156	0110	1110
35	53	65	0011	0101	6F	111	157	0110	1111
36	54	66	0011	0110	70	112	160	0111	0000
37	55	67	0011	0111	71	113	161	0111	0001
38	56	70	0011	1000	72	114	162	0111	0010
39	57	71	0011	1001	73	115	163	0111	0011

Table 7 (*Continued*)

Radix 16 Hexadecimal	Radix 10 Decimal	Radix 8 Octal	Radix 2 Binary		Radix 16 Hexadecimal	Radix 10 Decimal	Radix 8 Octal	Radix 2 Binary	
			BIT					BIT	
			8765	4321				8765	4321
74	116	164	0111	0100	D9	217	331	1101	1001
75	117	165	0111	0101	DA	218	332	1101	1010
76	118	166	0111	0110	DB	219	333	1101	1011
77	119	167	0111	0111	DC	220	334	1101	1100
78	120	170	0111	1000	DD	221	335	1101	1101
79	121	171	0111	1001	DE	222	336	1101	1110
7A	122	172	0111	1010	DF	223	337	1101	1111
7B	123	173	0111	1011	E0	224	340	1110	0000
7C	124	174	0111	1100	E1	225	341	1110	0001
7D	125	175	0111	1101	E2	226	342	1110	0010
7E	126	176	0111	1110	E3	227	343	1110	0011
7F	127	177	0111	1111	E4	228	344	1110	0100
80	128	200	1000	0000	E5	229	345	1110	0101
81	129	201	1000	0001	E6	230	346	1110	0110
82	130	202	1000	0010	E7	231	347	1110	0111
83	131	203	1000	0011	E8	232	350	1110	1000
84	132	204	1000	0100	E9	233	351	1110	1001
85	133	205	1000	0101	EA	234	352	1110	1010
86	134	206	1000	0110	EB	235	353	1110	1011
87	135	207	1000	0111	EC	236	354	1110	1100
88	136	210	1000	1000	ED	237	355	1110	1101
89	137	211	1000	1001	EE	238	356	1110	1110
8A	138	212	1000	1010	EF	239	357	1110	1111
8B	139	213	1000	1011	F0	240	360	1111	0000
8C	140	214	1000	1100	F1	241	361	1111	0001
8D	141	215	1000	1101	F2	242	362	1111	0010
8E	142	216	1000	1110	F3	243	363	1111	0011
8F	143	217	1000	1111	F4	244	364	1111	0100
90	144	220	1001	0000	F5	245	365	1111	0101
91	145	221	1001	0001	F6	246	366	1111	0110
92	146	222	1001	0010	F7	247	367	1111	0111
93	147	223	1001	0011	F8	248	370	1111	1000
94	148	224	1001	0100	F9	249	371	1111	1001
95	149	225	1001	0101	FA	250	372	1111	1010
96	150	226	1001	0110	FB	251	373	1111	1011
97	151	227	1001	0111	FC	252	374	1111	1100
98	152	230	1001	1000	FD	253	375	1111	1101
99	153	231	1001	1001	FE	254	376	1111	1110
9A	154	232	1001	1010	FF	255	377	1111	1111
9B	155	233	1001	1011	AB	171	253	1010	1011
9C	156	234	1001	1100	AC	172	254	1010	1100
9D	157	235	1001	1101	AD	173	255	1010	1101
9E	158	236	1001	1110	AE	174	256	1010	1110
9F	159	237	1001	1111	AF	175	257	1010	1111
A0	160	240	1010	0000	B0	176	260	1011	0000
A1	161	241	1010	0001	B1	177	261	1011	0001
A2	162	242	1010	0010	B2	178	262	1011	0010
A3	163	243	1010	0011	B3	179	263	1011	0011
A4	164	244	1010	0100	B4	180	264	1011	0100
A5	165	245	1010	0101	B5	181	265	1011	0101
A6	166	246	1010	0110	B6	182	286	1011	0110
A7	167	247	1010	0111	B7	183	267	1011	0111
A8	168	250	1010	1000	B8	184	270	1011	1000
A9	169	251	1010	1001	B9	185	271	1011	1001
AA	170	252	1010	1010	BA	186	272	1011	1010
D6	214	326	1101	0110	BB	187	273	1011	1011
D7	215	327	1101	0111	BC	188	274	1011	1100
D8	216	330	1101	1000	BD	189	275	1011	1101

(*Continues*)

Table 7 (*Continued*)

Radix 16 Hexadecimal	Radix 10 Decimal	Radix 8 Octal	Radix 2 Binary BIT 8765	4321	Radix 16 Hexadecimal	Radix 10 Decimal	Radix 8 Octal	Radix 2 Binary BIT 8765	4321
BE	190	276	1011	1110	CA	202	312	1100	1010
BF	191	277	1011	1111	CB	203	313	1100	1011
C0	192	300	1100	0000	CC	204	314	1100	1100
C1	193	301	1100	0001	CD	205	315	1100	1101
C2	194	302	1100	0010	CE	206	316	1100	1110
C3	195	303	1100	0011	CF	207	317	1100	1111
C4	196	304	1100	0100	D0	208	320	1101	0000
C5	197	305	1100	0101	D1	209	321	1101	0001
C6	198	306	1100	0110	D2	210	322	1101	0010
C7	199	307	1100	0111	D3	211	323	1101	0011
C8	200	310	1100	1000	D4	212	324	1101	0100
C9	201	311	1100	1001	D5	213	325	1101	0101

Table 8 Computer Graphics Codes and Standards

Modern computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-aided engineering (CAE) are heavily dependent on computer graphics. A standard computer graphics metafile (CGM) is necessary in order to:

1. Allow picture information to be stored in an organized way on a graphical software system.
2. Facilitate transfer of picture information between different graphical software systems.
3. Enable picture information to be transferred between graphical devices.
4. Enable picture information to be transferred between different computer graphics installations.

More particularly, the CGM should provide these capabilities in a device-independent manner. To accomplish this, the standard defines the form (syntax) and functional behavior (semantics) of a set of elements that may occur in the CGM. There are eight classes of elements:

1. Delimiter Elements — delimit significant structures within the metafile.
2. Metafile Descriptor Elements — describe the functional content, default conditions, identification, and characteristics of the CGM.
3. Picture Descriptor Elements — set the interpretation modes of attribute elements for each picture.
4. Control Elements — allow picture boundaries and coordinate representation to be modified.
5. Graphical Primitive Elements — describe the visual components of a picture in the CGM.
6. Attribute Elements — describe the appearance of graphical primitive elements.
7. Escape Elements — describe device- or system-dependent elements used to construct a picture; however, the elements are not otherwise standardized.
8. External Elements — communicate information not directly related to the generation of a graphical image.

A computer graphics metafile is a collection of elements from this standardized set. The BEGIN METAFILE and END METAFILE elements each occur exactly once in a complete metafile; as many or as few of the elements in the other classes may occur as are needed. A metafile needs to be interpreted in order to display its pictorial content on a graphics device. The descriptor elements give the interpreter sufficient data to interpret metafile elements and to make informed decisions concerning the resources needed for display.

A CGM contains delimiter elements; in addition it may include control elements for metafile interpretation, picture descriptor elements for declaring parameter modes of attribute elements, graphical primitive elements for defining graphical entities, attribute elements for defining the appearance of the graphical primitive elements, escape elements for accessing nonstandardized features of particular devices, and external elements for communication of information external to the definition of the pictures in the CGM.

Full description and depiction of all the elements thus far defined in this standardized set is beyond the scope of this handbook. The interested reader is referred to ANSI standard X3.122-1986 and Smith, B. M., et al. ''Initial Graphics Exchange Specification (IGES), Version 2.0,'' NBS (R82-2631) (AF) Feb. (1983) 26 pp.

2 MATHEMATICAL TABLES

Table 9 Certain Constants Containing e and π[a]

Powers of e			Multiples of π			Fractions of π		
e^n	Value	Logarithm	n_π	Value	Logarithm	π/n	Value	Logarithm
e	2.718282	0.434294	π	3.141593	0.497150	$\pi/2$	1.570780	0.196120
e^{-1}	0.367879	$\bar{1}.565706$	2π	6.283185	0.798180	$\pi/3$	1.047198	0.020029
e^2	7.389057	0.868589	3π	9.424778	0.974271	$\pi/4$	0.785398	$\bar{1}.895090$
e^{-2}	0.135335	$\bar{1}.131411$	4π	12.566371	1.099210	$\pi/180$	0.017453[b]	2.241877
$e^{1/2}$	1.648721	0.217147	5π	15.707963	1.196120			
Reciprocals of π			Powers of π			Roots of π		
n/π	Value	Logarithm	$\pi^{\pm n}$	Value	Logarithm	$\pi^{\pm 1/n}$	Value	Logarithm
$1/\pi$	0.318310	$\bar{1}.502850$	π^2	9.869604	0.994300	$\sqrt{\pi}$	1.772454	0.248575
$2/\pi$	0.636620	$\bar{1}.803880$	$1/\pi^2$	0.101321	$\bar{1}.005700$	$1/\sqrt{\pi}$	0.564190	$\bar{1}.751425$
$3/\pi$	0.954930	$\bar{1}.979971$	π^3	31.006277	1.491450	$\sqrt[3]{\pi}$	1.464592	0.165717
$180/\pi$	57.295780[c]	1.758123	$1/\pi^3$	0.032252	$\bar{2}.508550$	$1/\sqrt[3]{\pi}$	0.682784	$\bar{1}.834283$

[a] $e = 2.7182818285$; $\pi = 3.1415926536$; $M = \log_{10} e = 0.4342944819$; $M^{-1} = \log_e 10 = 2.3025850930$.
[b] Number of radians per degree.
[c] Number of degrees per radian.

Table 10 Factorials

n	$n! = 1 \cdot 2 \cdot 3 \cdots n$	$1/n!$	n	$n! = 1 \cdot 2 \cdot 3 \cdots n$	$1/n!$
1	1	1.	11	$399{,}168 \times 10^2$	0.250521×10^{-7}
2	2	0.5	12	$479{,}002 \times 10^3$	0.208768×10^{-8}
3	6	0.166667	13	$622{,}702 \times 10^4$	0.160590×10^{-9}
4	24	0.416667×10^{-1}	14	$871{,}783 \times 10^5$	0.114707×10^{-10}
5	120	0.833333×10^{-2}	15	$130{,}767 \times 10^7$	0.764716×10^{-12}
6	720	0.138889×10^{-2}	16	$209{,}228 \times 10^8$	0.477948×10^{-13}
7	5,040	0.198413×10^{-3}	17	$355{,}687 \times 10^9$	0.281146×10^{-14}
8	40,320	0.248016×10^{-4}	18	$640{,}237 \times 10^{10}$	0.156192×10^{-15}
9	362,880	0.275573×10^{-5}	19	$121{,}645 \times 10^{12}$	0.822064×10^{-17}
10	3,628,800	0.275573×10^{-6}	20	$243{,}290 \times 10^{13}$	0.411032×10^{-19}

Table 11 Common and Natural Logarithms of Numbers

The common logarithm of a number is the index of the power to which the base 10 must be raised in order to equal the number.

The common logarithm of every positive number not an integral power of 10 consists of an *integral* and a *decimal part*. The integral part or whole number is called the *characteristic* and may be either *positive* or *negative*. The decimal or fractional part is a positive number called the *mantissa* and is the same for all numbers which have the same sequential digits.

The characteristic of the logarithm of any positive number greater than 1 is positive and is 1 less than the number of digits before the decimal point.

The characteristic of the logarithm of any positive number less than 1 is negative and is 1 more than the number of ciphers immediately after the decimal point.

A negative number or number less than zero has no real logarithm.

Examples: $\log_{10} 25{,}400. = 4.404834$, $\log_{10} 0.0254 = \bar{2}.404834$, or $8.404834 - 10$

(*Continues*)

Table 11 (*Continued*)

The two systems of logarithms in general use are the common or Briggsian logarithms, introduced in 1615 by Henry Briggs, a contemporary of John Napier, the inventor of logarithms, and the natural or less appropriately termed Napierian or hyperbolic logarithms, which developed somewhat accidentally from Napier's original work. The latter have a base denoted by e, an irrational number, which is

$$\lim_{u=\infty}\left(1+\frac{1}{u}\right)^{u} = 1+1+\frac{1}{2!}+\frac{1}{3!}+\frac{1}{4!}+\cdots = 2.7182818$$

To obtain the natural logarithm, the common logarithm is multiplied by $\log_e 10$, which is 2.302585, or $\log_e N = 2.302585 \log_{10} N$.

The natural logarithm of a number is the index of the power to which the base e ($= 2.7182818$) must be raised in order to equal the number.

Example: $\log_e 4.12 = \ln\ 4.12 = 1.4159$.

Natural logarithms of numbers from 1.00 to 9.99 may be obtained directly; the natural logarithms of numbers outside of that range by the addition or subtraction of the natural logarithms of powers of 10.

Examples:
$\log_e 679. \;= \log_e 6.79 + \log_e 10^2 = 1.9155 + 4.6052 = 6.5207.$
$\log_e 0.0679 = \log_e 6.79 - \log_e 10^2 = 1.9155 - 4.6052 = -2.6897$

Natural Logarithms of Powers of 10

$\log_e 10 = 2.302\,585$	$\log_e 10^4 = 9.210\,340$	$\log_e 10^7 = 16.118\,096$
$\log_e 10^2 = 4.605\,170$	$\log_e 10^5 = 11.512\,925$	$\log_e 10^8 = 18.420\,681$
$\log_e 10^3 = 6.907\,755$	$\log_e 10^6 = 13.815\,511$	$\log_e 10^9 = 20.723\,266$

To obtain the common logarithm, the natural logarithm is multiplied by $\log_{10} e$, which is 0.434294, or $\log_{10} N = 0.434294 \log_e N$.

A negative number or number less than zero has no real logarithm.

Tabulations of common and natural logarithms are no longer provided in this handbook because of ready access to them on modern pocket and desk calculators.

Values and Logarithms of Exponentials and Hyperbolic Functions

Many calculators directly give values of e^x, e^{-x}, $\sinh x$, $\cosh x$, and $\tanh x$ for any value of x. These quantities are therefore not tabulated here.

For values of x greater than 6, e^x may be computed from the relationship $e^x = \log^{-1}(x\ \log_{10}\ e) = \log^{-1} 0.43429x$; e^{-x} approaches zero; $\sinh x$ and $\cosh x$ are approximately equal and become $0.5e^x$; and $\tanh x$ and $\coth x$ have values approximately equal to unity.

Where more accurate values of the exponentials and functions are required they may be computed from the following relationships:

$$e = 2.7182818285 \qquad \frac{1}{e} = 0.3678794412$$

$$M = \log_{10} e = 0.4342944819 \qquad \frac{1}{M} = \log_e 10 = 2.3025850930$$

$$e^x = \log^{-1} Mx \qquad e^{-x} = \log^{-1}(-Mx)$$

$$\sinh x = \frac{e^x - e^{-x}}{2} \qquad \cosh x = \frac{e^x + e^{-x}}{2} \qquad \tanh x = \frac{e^x - e^{-x}}{e^x + e^{-x}}$$

$$\operatorname{csch} x = \frac{1}{\sinh x} \qquad \operatorname{sech} x = \frac{1}{\cosh x} \qquad \coth x = \frac{1}{\tanh x}$$

Table 11 (*Continued*)

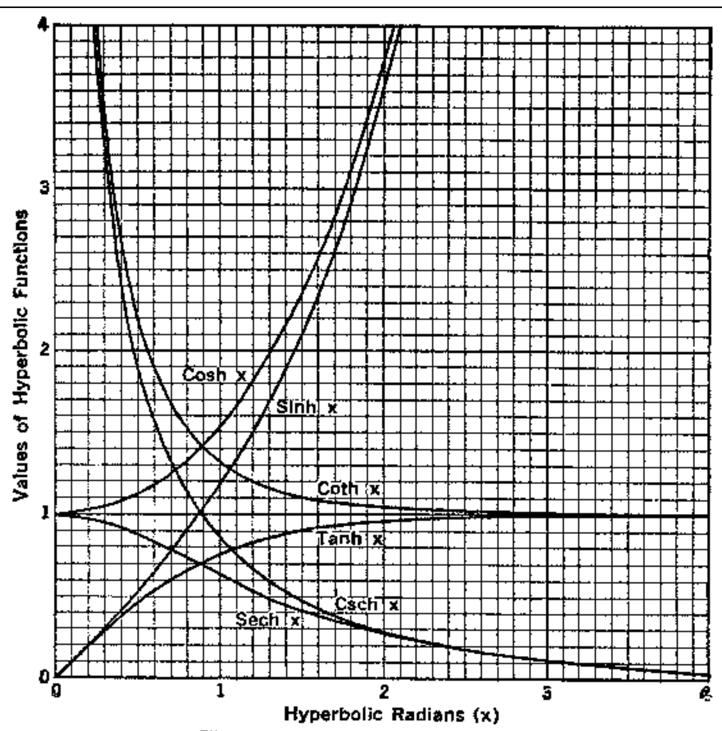


Chart of the Hyperbolic Functions.

Values of the hyperbolic functions are shown in the figure.

Table 12 Circular Arcs, Chords, and Segments

Central Angle in Degrees	Arc / R	Height / R	Chord / R	Height / Chord	Area / R^2	Central Angle in Degrees	Arc / R	Height / R	Chord / R	Height / Chord	Area / R^2
1	0.0175	0.0000	0.0175	0.0022	0.00000	21	0.3665	0.0167	0.3645	0.0459	0.00408
2	0.0349	0.0002	0.0349	0.0044	0.00000	22	0.3840	0.0184	0.3816	0.0481	0.00468
3	0.0524	0.0003	0.0524	0.0066	0.00001	23	0.4014	0.0201	0.3987	0.0503	0.00535
4	0.0698	0.0006	0.0698	0.0087	0.00003	24	0.4189	0.0219	0.4158	0.0526	0.00607
5	0.0873	0.0010	0.0872	0.0109	0.00006	25	0.4363	0.0237	0.4329	0.0548	0.00686
6	0.1047	0.0014	0.1047	0.0131	0.00010	26	0.4538	0.0256	0.4499	0.0570	0.00771
7	0.1222	0.0019	0.1221	0.0153	0.00015	27	0.4712	0.0276	0.4669	0.0592	0.00862
8	0.1396	0.0024	0.1395	0.0175	0.00023	28	0.4887	0.0297	0.4838	0.0614	0.00961
9	0.1571	0.0031	0.1569	0.0196	0.00032	29	0.5061	0.0319	0.5008	0.0636	0.01067
10	**0.1745**	**0.0038**	**0.1743**	**0.0218**	**0.00044**	**30**	**0.5236**	**0.0341**	**0.5176**	**0.0658**	**0.1180**
11	0.1920	0.0046	0.1917	0.0240	0.00059	31	0.5411	0.0364	0.5345	0.0680	0.01301
12	0.2094	0.0055	0.2091	0.0262	0.00076	32	0.5585	0.0387	0.5513	0.0703	0.01429
13	0.2296	0.0064	0.2264	0.0284	0.00097	33	0.5760	0.0412	0.5680	0.0725	0.01566
14	0.2443	0.0075	0.2437	0.0306	0.00121	34	0.5934	0.0437	0.5847	0.0747	0.01711
15	0.2618	0.0086	0.2611	0.0328	0.00149	35	0.6109	0.0463	0.6014	0.0770	0.01864
16	0.2793	0.0097	0.2783	0.0350	0.00181	36	0.6283	0.0489	0.6180	0.0792	0.02027
17	0.2967	0.0110	0.2956	0.0372	0.00217	37	0.6458	0.0517	0.6346	0.0814	0.02198
18	0.3142	0.0123	0.3129	0.0394	0.00257	38	0.6632	0.0545	0.6511	0.0837	00.2378
19	0.3316	0.0137	0.3301	0.0415	0.00302	39	0.6807	0.0574	0.6676	0.0859	0.02568
20	**0.3491**	**0.0152**	**0.3473**	**0.0437**	**0.00352**	**40**	**0.6981**	**0.0603**	**0.6840**	**0.0882**	**0.02767**

(*Continues*)

Table 12 (*Continued*)

Central Angle in Degrees	Arc / R	Height / R	Chord / R	Height / Chord	Area / R^2	Central Angle in Degrees	Arc / R	Height / R	Chord / R	Height / Chord	Area / R^2
41	0.7156	0.0633	0.7004	0.0904	0.02976	101	1.7628	0.3639	1.543	0.2358	0.39058
42	0.7330	0.0664	0.7167	0.0927	0.03195	102	1.7802	0.3707	1.554	0.2385	0.40104
43	0.7505	0.0696	0.7330	0.0949	0.03425	103	1.7977	0.3775	1.565	0.2412	0.41166
44	0.7679	0.0728	0.7492	0.0972	0.03664	104	1.8151	0.3843	1.576	0.2439	0.42242
45	0.7854	0.0761	0.7654	0.0995	0.03915	105	1.8326	0.3912	1.587	0.2466	0.43333
46	0.8029	0.0795	0.7815	0.1017	0.04176	106	1.8500	0.3982	1.597	0.2493	0.44439
47	0.8203	0.0829	0.7975	0.1040	0.04448	107	1.8675	0.4052	1.608	0.2520	0.45560
48	0.8378	0.0865	0.8135	0.1063	0.04731	108	1.8850	0.4122	1.618	0.2548	0.46695
49	0.8552	0.0900	0.8294	0.1086	0.05025	109	1.9024	0.4193	1.628	0.2575	0.47844
50	**0.8727**	**0.0937**	**0.8452**	**0.1108**	**0.05331**	**110**	**1.9199**	**0.4264**	**1.638**	**0.2603**	**0.49008**
51	0.8901	0.0974	0.8610	0.1131	0.05649	111	1.9373	0.4336	1.648	0.2631	0.50187
52	0.9076	0.1012	0.8767	0.1154	0.05978	112	1.9548	0.4408	1.658	0.2659	0.51379
53	0.9250	0.1051	0.8924	0.1177	0.06319	113	1.9722	0.4481	1.668	0.2687	0.52586
54	0.9425	0.1090	0.9080	0.1200	0.06673	114	1.9897	0.4554	1.677	0.2715	0.53807
55	0.9599	0.1130	0.9235	0.1223	0.07039	115	2.0071	0.4627	1.687	0.2743	0.55041
56	0.9774	0.1171	0.9389	0.1247	0.07417	116	2.0246	0.4701	1.696	0.2772	0.56289
57	0.9948	0.1212	0.9543	0.1270	0.07808	117	2.0420	0.4775	1.705	0.2800	0.57551
58	1.0123	0.1254	0.9696	0.1293	0.08212	118	2.0595	0.4850	1.714	0.2829	0.58827
59	1.0297	0.1296	0.9848	0.1316	0.08629	119	2.0769	0.4925	1.723	0.2858	0.60116
60	**1.0472**	**0.1340**	**1.0000**	**0.1340**	**0.09059**	**120**	**2.0944**	**0.5000**	**1.732**	**0.2887**	**0.61418**
61	1.0647	0.1384	1.015	0.1363	0.09502	121	2.1118	0.5076	1.741	0.2916	0.62734
62	1.0821	0.1428	1.030	0.1387	0.09958	122	2.1293	0.5152	1.749	0.2945	0.64063
63	1.0996	0.1474	1.045	0.1410	0.10428	123	2.1468	0.5228	1.758	0.2975	0.65404
64	1.1170	0.1520	1.060	0.1434	0.10911	124	2.1642	0.5305	1.766	0.3004	0.66759
65	1.1345	0.1566	1.075	0.1457	0.11408	125	2.1817	0.5383	1.774	0.3034	0.68125
66	1.1519	0.1613	1.089	0.1481	0.11919	126	2.1991	0.5460	1.782	0.3064	0.69505
67	1.1694	0.1661	1.104	0.1505	0.12443	127	2.2166	0.5538	1.790	0.3094	0.70897
68	1.1868	0.1710	1.118	0.1529	0.12982	128	2.2340	0.5616	1.798	0.3124	0.72301
69	1.2043	0.1759	1.133	0.1553	0.13535	129	2.2515	0.5695	1.805	0.3155	0.73716
70	**1.2217**	**0.1808**	**1.147**	**0.1576**	**0.14102**	**130**	**2.2689**	**0.5774**	**1.813**	**0.3185**	**0.75143**
71	1.2392	0.1859	1.161	0.1601	0.14683	131	2.2864	0.5853	1.820	0.3216	0.76584
72	1.2566	0.1910	1.176	0.1625	0.15279	132	2.3038	0.5933	1.827	0.3247	0.78034
73	1.2741	0.1961	1.190	0.1649	0.15889	133	2.3213	0.6013	1.834	0.3278	0.79497
74	1.2915	0.2014	1.204	0.1673	0.16514	134	2.3387	0.6093	1.841	0.3309	0.80970
75	1.3090	0.2066	1.218	0.1697	0.17154	135	2.3562	0.6173	1.848	0.3341	0.82454
76	1.3265	0.2120	1.231	0.1722	0.17808	136	2.3736	0.6254	1.854	0.3373	0.83949
77	1.3439	0.2174	1.245	0.1746	0.18477	137	2.3911	0.6335	1.861	0.3404	0.85455
78	1.3614	0.2229	1.259	0.1771	0.19160	138	2.4086	0.6416	1.867	0.3436	0.86971
79	1.3788	0.2284	1.272	0.1795	0.19859	139	2.4260	0.6498	1.873	0.3469	0.88497
80	**1.3963**	**0.2340**	**1.286**	**0.1820**	**0.20573**	**140**	**2.4435**	**0.6580**	**1.879**	**0.3501**	**0.90034**
81	1.4137	0.2396	1.299	0.1845	0.21301	141	2.4609	0.6662	1.885	0.3534	0.91580
82	1.4312	0.2453	1.312	0.1869	0.22045	142	2.4784	0.6744	1.891	0.3566	0.93135
83	1.4486	0.2510	1.325	0.1894	0.22804	143	2.4958	0.6827	1.897	0.3599	0.94700
84	1.4661	0.2569	1.338	0.1919	0.23578	144	2.5133	0.6910	1.902	0.3633	0.96274
85	1.4835	0.2627	1.351	0.1944	0.24367	145	2.5307	0.6993	1.907	0.3666	0.97858
86	1.5010	0.2686	1.364	0.1970	0.25171	146	2.5482	0.7076	1.913	0.3700	0.99449
87	1.5184	0.2746	1.377	0.1995	0.25990	147	2.5656	0.7160	1.918	0.3734	1.0105
88	1.5359	0.2807	1.389	0.2020	0.26825	148	2.5831	0.7244	1.923	0.3768	1.0266
89	1.5533	0.2867	1.402	0.2046	0.27675	149	2.6005	0.7328	1.927	0.3802	1.0428
90	**1.5708**	**0.2929**	**1.414**	**0.2071**	**0.28540**	**150**	**2.6180**	**0.7412**	**1.932**	**0.3837**	**1.0590**
91	1.5882	0.2991	1.427	0.2097	0.29420	151	2.6354	0.7496	1.936	0.3871	1.0753
92	1.6057	0.3053	1.439	0.2122	0.30316	152	2.6529	0.7581	1.941	0.3906	1.0917
93	1.6232	0.3116	1.451	0.2148	0.31226	153	2.6704	0.7666	1.945	0.3942	1.1082
94	1.6406	0.3180	1.463	0.2174	0.32152	154	2.6878	0.7750	1.949	0.3977	1.1247
95	1.6581	0.3244	1.475	0.2200	0.33093	155	2.7053	0.7836	1.953	0.4013	1.1413
96	1.6755	0.3309	1.486	0.2226	0.34050	156	2.7227	0.7921	1.956	0.4049	1.1580
97	1.6930	0.3374	1.498	0.2252	0.35021	157	2.7402	0.8006	1.960	0.4085	1.1747
98	1.7104	0.3439	1.509	0.2279	0.36008	158	2.7576	0.8092	1.963	0.4122	1.1915
99	1.7279	0.3506	1.521	0.2305	0.37009	159	2.7751	0.8178	1.967	0.4158	1.2084
100	**1.7453**	**0.3572**	**1.532**	**0.2332**	**0.38026**	**160**	**2.7925**	**0.8264**	**1.970**	**0.4195**	**1.2253**

Table 12 (*Continued*)

Central Angle in Degrees	Arc / R	Height / R	Chord / R	Height / Chord	Area / R^2	Central Angle in Degrees	Arc / R	Height / R	Chord / R	Height / Chord	Area / R^2
161	2.8100	0.8350	1.973	0.4233	1.2422	171	2.9845	0.9215	1.994	0.4622	1.4140
162	2.8274	0.8436	1.975	0.4270	1.2592	172	3.0020	0.9302	1.995	0.4663	1.4314
163	2.8449	0.8522	1.978	0.4308	1.2763	173	3.0194	0.9390	1.996	0.4704	1.4488
164	2.8623	0.8608	1.981	0.4346	1.2934	174	3.0369	0.9477	1.997	0.4745	1.4662
165	2.8798	0.8695	1.983	0.4385	1.3105	175	3.0543	0.9564	1.998	0.4786	1.4836
166	2.8972	0.8781	1.985	0.4424	1.3277	176	3.0718	0.9651	1.999	0.4828	1.5010
167	2.9147	0.8868	1.987	0.4463	1.3449	177	3.0892	0.9738	1.999	0.4871	1.5184
168	2.9322	0.8955	1.989	0.4502	1.3621	178	3.1067	0.9825	2.000	0.4914	1.5359
169	2.9496	0.9042	1.991	0.4542	1.3794	179	3.1241	0.9913	2.000	0.4957	1.5533
170	**2.9671**	**0.9128**	**1.992**	**0.4582**	**1.3967**	**180**	**3.1416**	**1.0000**	**2.000**	**0.5000**	**1.5708**

Table 13 Values of Degrees, Minutes, and Seconds in Radians[a]

Degrees	Radians Arc Length $R = 1$	Degrees	Radians Arc Length $R = 1$	Degrees	Radians Arc Length $R = 1$		Radians Arc Length $R = 1$ Minutes	Seconds
0		**40**	**0.69813170**	**80**	**1.39626340**	**0**		
1	0.01745329	41	0.71558499	81	1.41371669	1	0.00029089	0.00000485
2	0.03490659	42	0.73303829	82	1.43116999	2	0.00058178	0.00000970
3	0.05235988	43	0.75049158	83	1.44862328	3	0.00087266	0.00001454
4	0.06981317	44	0.76794487	84	1.46607657	4	0.00116355	0.00001939
5	0.08726646	45	0.78539816	85	1.48352986	5	0.00145444	0.00002424
6	0.10471976	46	0.80285146	86	1.50098316	6	0.00174533	0.00002909
7	0.12217305	47	0.82030475	87	1.51843645	7	0.00203622	0.00003394
8	0.13962634	48	0.83775804	88	1.53588974	8	0.00232711	0.00003879
9	0.15707963	49	0.85521133	89	1.55334303	9	0.00261799	0.00004363
10	**0.17453293**	**50**	**0.87266463**	**90**	**1.57079633**	**10**	**0.00290888**	**0.00004848**
11	0.19198622	51	0.89011792	91	1.58824962	11	0.00319977	0.00005333
12	0.20943951	52	0.90757121	92	1.60570291	12	0.00349066	0.00005818
13	0.22689280	53	0.92502450	93	1.62315620	13	0.00378155	0.00006303
14	0.24434610	54	0.94247780	94	1.64060950	14	0.00407243	0.000068787
15	0.26179939	55	0.95993109	95	1.65806279	15	0.00436332	0.00007272
16	0.27925268	56	0.97738438	96	1.67551608	16	0.00465421	0.00007757
17	0.29670597	57	0.99483767	97	1.69296937	17	0.00494510	0.00008242
18	0.31415927	58	1.01229097	98	1.71042267	18	0.00523599	0.00008727
19	0.33161256	59	1.02974426	99	1.72787596	19	0.00552688	0.00009211
20	**0.34906585**	**60**	**1.04719755**	**100**	**1.74532925**	**20**	**0.00581776**	**0.00009696**
21	0.36651914	61	1.06465084	101	1.76278254	21	0.00610865	0.00010181
22	0.38397244	62	1.08210414	102	1.78023584	22	0.00639954	0.00010666
23	0.40142573	63	1.09955743	103	1.79768913	23	0.00669043	0.00011151
24	0.41887902	64	1.11701072	104	1.81514242	24	0.00698132	0.00011636
25	0.43633231	65	1.13446401	105	1.83259571	25	0.00727221	0.00012120
26	0.45378561	66	1.15191731	106	1.85004901	26	0.00756309	0.00012605
27	0.47123890	67	1.16937060	107	1.86750230	27	0.00785398	0.00013090
28	0.48869219	68	1.18682389	108	1.88495559	28	0.00814487	0.00013575
29	0.50614548	69	1.20427718	109	1.90240888	29	0.00843576	0.00014060
30	**0.52359878**	**70**	**1.22173048**	**110**	**1.91986218**	**30**	**0.00872665**	**0.00014544**
31	0.54105207	71	1.23918377	111	1.93731547	31	0.00901753	0.00015029
32	0.55850536	72	1.25663706	112	1.95476876	32	0.00930842	0.00015514
33	0.57595865	73	1.27409035	113	1.97222205	33	0.00959931	0.00015999
34	0.59341195	74	1.29154365	114	1.98967535	34	0.00989020	0.00016484
35	0.61086524	75	1.30899694	115	2.00712864	35	0.01018109	0.00016968
36	0.62831853	76	1.32645023	116	2.02458193	36	0.01047198	0.00017453
37	0.64577182	77	1.34390352	117	2.04203522	37	0.01076286	0.00017938
38	0.66322512	78	1.36135682	118	2.05948852	38	0.01105375	0.00018423
39	0.68067841	79	1.37881011	119	2.07694181	39	0.01134464	0.00018908

(*Continues*)

Table 13 (*Continued*)

Degrees	Radians Arc Length $R = 1$	Degrees	Radians Arc Length $R = 1$	Degrees	Radians Arc Length $R = 1$		Radians Arc Length $R = 1$ Minutes	Seconds
120	**2.09439510**	**140**	**2.44346095**	**160**	**2.79252680**	**40**	**0.01163553**	**0.00019393**
121	2.11184840	141	2.46091424	161	2.80998009	41	0.01192642	0.00019877
122	2.12930169	142	2.47836754	162	2.82743338	42	0.01221730	0.00020362
123	2.14675498	143	2.49582083	163	2.84488668	43	0.01250819	0.00020847
124	2.16420828	144	2.51327413	164	2.86233997	44	0.01279908	0.00021332
125	2.18166157	145	2.53072742	165	2.87979327	45	0.01308997	0.00021817
126	2.19911486	146	2.54818071	166	2.89724655	46	0.01338086	0.00022301
127	2.21656815	147	2.56563401	167	2.91469985	47	0.01367175	0.00022786
128	2.23402145	148	2.58308729	168	2.93215314	48	0.01396263	0.00023271
129	2.25147474	149	2.60054058	169	2.94960643	49	0.01425352	0.00023756
130	**2.26892803**	**150**	**2.61799388**	**170**	**2.96705972**	**50**	**0.01454441**	**0.00024241**
131	2.28638133	151	2.63544717	171	2.98451302	51	0.01483530	0.00024725
132	2.30383462	152	2.65290046	172	3.00196631	52	0.01512619	0.00025210
133	2.32128791	153	2.67035375	173	3.01941961	53	0.01541707	0.00025695
134	2.33874121	154	2.68780705	174	3.03687289	54	0.01570796	0.00026180
135	2.35619450	155	2.70526034	175	3.05432619	55	0.01599885	0.00026665
136	2.37364780	156	2.72271363	176	3.07177948	56	0.01628974	0.00027150
137	2.39110107	157	2.74016693	177	3.08923277	57	0.01658063	0.00027634
138	2.40855436	158	2.75762022	178	3.10668607	58	0.01687152	0.00028119
139	2.42600766	159	2.77507351	179	3.12413962	59	0.01716240	0.00028604
				180	**3.14159265**			

[a]Lengths of circular arcs, radius unity, for example:

$$\Theta = 30^\circ 20' 10''$$
$$30^\circ = 0.52359878$$
$$20' = 0.00581776$$
$$10'' = \underline{0.00004848}$$
$$\text{Arc length} = 0.52946502 \text{ radians}$$

Table 14 Values of Radians in Degrees

Radian	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.5730	1.1459	1.7189	2.2918	2.8648	3.4377	4.0107	4.5837	5.1566
0.1	5.7296	6.3025	6.8755	7.4485	8.0214	8.5944	9.1673	9.7403	10.3132	10.8862
0.2	11.4591	12.0321	12.6051	13.1780	13.7510	14.3239	14.8969	15.4699	16.0428	16.6158
0.3	17.1887	17.7617	18.3346	18.9076	19.4806	20.0535	20.6265	21.1994	21.7724	22.3454
0.4	22.9183	23.4913	24.0642	24.6372	25.2101	25.7831	26.3561	26.9290	27.5020	28.0749
0.5	28.6479	29.2208	29.7938	30.3668	30.9397	31.1527	32.0856	32.6586	33.2316	33.8045
0.6	34.3775	34.9504	35.5234	36.0963	36.6693	37.2423	37.8152	38.3882	38.9611	39.5341
0.7	40.1070	40.6800	41.2530	41.8259	42.3989	42.9718	43.5448	44.1178	44.6907	45.2637
0.8	45.8366	46.4096	46.9825	47.5555	48.1285	48.7014	49.2744	49.8473	50.4203	50.9932
0.9	51.5662	52.1392	52.7121	53.2851	53.8580	54.4310	55.0039	55.5769	56.1499	56.7228

1 rad = 57.29578° 2 rads = 114.59156° 3 rads = 171.88734°

Table 15 Decimals of a Degree in Minutes and Seconds

Decimal \ Decimal	0.00 Min	Sec	0.01 Min	Sec	0.02 Min	Sec	0.03 Min	Sec	0.04 Min	Sec	0.05 Min	Sec	0.06 Min	Sec	0.07 Min	Sec	0.08 Min	Sec	0.09 Min	Sec
0.0	0	0	0	36	1	12	1	48	2	24	3	0	3	36	4	12	4	48	5	24
0.1	6	0	6	36	7	12	7	48	8	24	9	0	9	36	10	12	10	48	11	24
0.2	12	0	12	36	13	12	13	48	14	24	15	0	15	36	16	12	16	48	17	24
0.3	18	0	18	36	19	12	19	48	20	24	21	0	21	36	22	12	22	48	23	24
0.4	24	0	24	36	25	12	25	48	26	24	27	0	27	36	28	12	28	48	29	24

(*Continues*)

Table 15 (*Continued*)

Decimal \ Decimal	0.00		0.01		0.02		0.03		0.04		0.05		0.06		0.07		0.08		0.09	
	Min	Sec	Min	Sec	Min	Sec	Min	Sec	Min	Sec	Min	Sec	Min	Sec	Min	Sec	Min	Sec	Min	Sec
0.5	30	0	30	36	31	12	31	48	32	24	33	0	33	36	34	12	34	48	35	24
0.6	36	0	36	36	37	12	37	48	38	24	39	0	39	36	40	12	40	48	41	24
0.7	42	0	42	36	43	12	43	48	44	24	45	0	45	36	46	12	46	48	47	24
0.8	48	0	48	36	49	12	49	48	50	24	51	0	51	36	52	12	52	48	53	24
0.9	54	0	54	36	55	12	55	48	56	24	57	0	57	36	58	12	58	48	59	24

Table 16 Minutes in Decimals of a Degree

Minutes	0	1	2	3	4	5	6	7	8	9
0	0.00000	0.01667	0.03333	0.05000	0.06667	0.08333	0.10000	0.11667	0.13333	0.15000
10	0.16667	0.18333	0.20000	0.21667	0.23333	0.25000	0.26667	0.28333	0.30000	0.31667
20	0.33333	0.35000	0.36667	0.38333	0.40000	0.41667	0.43333	0.45000	0.46667	0.48333
30	0.50000	0.51667	0.53333	0.55000	0.56667	0.58333	0.60000	0.61667	0.63333	0.65000
40	0.66667	0.68333	0.70000	0.71667	0.73333	0.75000	0.76667	0.78333	0.80000	0.81667
50	0.83333	0.85000	0.86667	0.88333	0.90000	0.91667	0.93333	0.95000	0.96667	0.98333

Table 17 Seconds in Decimals of a Degree

Seconds	0	1	2	3	4
0	0	0.0002778	0.0005555	0.0008333	0.0011111
10	0.0027778	0.0030555	0.0033333	0.0036111	0.0038888
20	0.0055555	0.0058333	0.0061111	0.0063888	0.0066667
30	0.0083333	0.0086111	0.0088888	0.0091667	0.0094444
40	0.0111111	0.0113888	0.0116667	0.0119444	0.0122222
50	0.0138888	0.0141667	0.0144444	0.0147222	0.0150000
Seconds	**5**	**6**	**7**	**8**	**9**
0	0.0013888	0.0016667	0.0019444	0.0022222	0.0024999
10	0.0041667	0.0044444	0.0047222	0.0050000	0.0052778
20	0.0069444	0.0072222	0.0075000	0.0077778	0.0080555
30	0.0097222	0.0100000	0.0102778	0.0105555	0.0108333
40	0.0125000	0.0127778	0.0130555	0.0133333	0.0136111
50	0.0152778	0.0155555	0.0158333	0.0161111	0.0163888

Table 18 Table of Integrals

Elementary Indefinite Integrals

1. $\int a\, dx = ax$
2. $\int (u + v + w + \cdots)\, dx = \int u\, dx + \int v\, dx + \int w\, dx + \cdots$
3. $\int u\, dv = uv - \int v\, du$, integration by parts
4. $\int f(x)\, dx = \int f[\phi(y)]\phi'(y)\, dy,\ x = \phi(y)$, change of variable
5. $\int x^n\, dx = \dfrac{x^{n+1}}{n+1} \quad (n \neq -1)$
6. $\int \dfrac{dx}{x} = \log_e x + c = \log_e c_1 x,\ [\log_e x = \log_e(-x) + (2k+1)\pi i]$
7. $\int e^{ax}\, dx = \dfrac{1}{a} e^{ax}$

(*Continues*)

Table 18 (*Continued*)

Elementary Indefinite Integrals (Continued)

8. $\int a^x\,dx = \dfrac{a^x}{\log_e a}$

9. $\int a^x \log_e a\,dx = a^x.$

10. $\int \sin ax\,dx = -\dfrac{1}{a}\cos ax$

11. $\int \cos ax\,dx = \dfrac{1}{a}\sin ax$

12. $\int \tan ax\,dx = -\dfrac{1}{a}\log_e \cos ax = \dfrac{1}{a}\log_e \sec ax$

13. $\int \cot ax\,dx = \dfrac{1}{a}\log_e \sin ax = -\dfrac{1}{a}\log_e \csc ax$

14. $\int \sec ax\,dx = \dfrac{1}{a}\log_e(\sec ax + \tan ax) = \dfrac{1}{a}\log_e \tan\left(\dfrac{ax}{2} + \dfrac{\pi}{4}\right)$

15. $\int \csc ax\,dx = \dfrac{1}{a}\log_e(\csc ax - \cot ax) = \dfrac{1}{a}\log_e \tan\dfrac{ax}{2}$

16. $\int \dfrac{dx}{\sqrt{a^2 - x^2}} = \sin^{-1}\dfrac{x}{a} = -\cos^{-1}\dfrac{x}{a} \quad (x^2 < a^2)$

17. $\int \dfrac{dx}{a^2 + x^2} = \dfrac{1}{a}\tan^{-1}\dfrac{x}{a} = -\dfrac{1}{a}\cot^{-1}\dfrac{x}{a}$

18. $\int \sinh ax\,dx = \dfrac{1}{a}\cosh ax$

19. $\int \cosh ax\,dx = \dfrac{1}{a}\sinh ax$

20. $\int \tanh ax\,dx = \dfrac{1}{a}\log_e(\cosh ax)$

21. $\int \coth ax\,dx = \dfrac{1}{a}\log_e(\sinh ax)$

22. $\int \operatorname{sech} ax\,dx = \dfrac{1}{a}\sin^{-1}(\tanh ax) = \dfrac{1}{a}\tan^{-1}(\sinh ax)$

23. $\int \operatorname{csch} ax\,dx = \dfrac{1}{a}\log_e\left(\tanh\dfrac{ax}{2}\right)$

24. $\int \sin^2 ax\,dx = \dfrac{1}{2}x - \dfrac{1}{2a}\sin ax\cos ax = \dfrac{1}{2}x - \dfrac{1}{4a}\sin 2ax$

25. $\int \cos^2 ax\,dx = \dfrac{1}{2}x + \dfrac{1}{2a}\sin ax\cos ax = \dfrac{1}{2}x + \dfrac{1}{4a}\sin 2ax$

26. $\int \tan^2 ax\,dx = \dfrac{1}{a}\tan ax - x$

27. $\int \cot^2 ax\,dx = -\dfrac{1}{a}\cot ax - x$

28. $\int \sec^2 ax\,dx = \dfrac{1}{a}\tan ax$

29. $\int \csc^2 ax\,dx = -\dfrac{1}{a}\cot ax$

30. $\int \sin^{-1} ax\,dx = x\sin^{-1} ax + \dfrac{1}{a}\sqrt{1 - a^2x^2}$

31. $\int \cos^{-1} ax\,dx = x\cos^{-1} ax - \dfrac{1}{a}\sqrt{1 - a^2x^2}$

32. $\int \tan^{-1} ax\,dx = x\tan^{-1} ax - \dfrac{1}{2a}\log_e(1 + a^2x^2)$

Table 18 (*Continued*)

Elementary Indefinite Integrals (Continued)

33. $\int \cot^{-1} ax\, dx = x \cot^{-1} ax + \frac{1}{2a} \log_e(1 + a^2x^2)$

34. $\int \sec^{-1} ax\, dx = x \sec^{-1} ax - \frac{1}{a} \log_e(ax + \sqrt{a^2x^2 - 1})$

35. $\int \csc^{-1} ax\, dx = x \csc^{-1} ax + \frac{1}{a} \log_e(ax + \sqrt{a^2x^2 - 1})$

Integrals Involving $ax + b$

36. $\int (ax+b)^n\, dx = \frac{1}{a(n+1)}(ax+b)^{n+1} \quad (n \neq -1)$

37. $\int \frac{dx}{ax+b} = \frac{1}{a} \log_e(ax+b)$

38. $\int x(ax+b)^n\, dx = \frac{1}{a^2(n+2)}(ax+b)^{n+2} - \frac{b}{a^2(n+1)}(ax+b)^{n+1} \quad (n \neq -1, -2)$

39. $\int \frac{x\, dx}{ax+b} = \frac{x}{a} - \frac{b}{a^2} \log_e(ax+b)$

40. $\int \frac{x\, dx}{(ax+b)^2} = \frac{b}{a^2(ax+b)} + \frac{1}{a^2} \log_e(ax+b)$

41. $\int \frac{x^2\, dx}{ax+b} = \frac{1}{a^3}\left[\frac{1}{2}(ax+b)^2 - 2b(ax+b) + b^2 \log_e(ax+b)\right]$

42. $\int \frac{x^2\, dx}{(ax+b)^2} = \frac{1}{a^3}\left[(ax+b) - 2b \log_e(ax+b) - \frac{b^2}{ax+b}\right]$

43. $\int \frac{x^2\, dx}{(ax+b)^3} = \frac{1}{a^3}\left[\log_e(ax+b) + \frac{2b}{ax+b} - \frac{b^2}{2(ax+b)^2}\right]$

44. $\int \frac{dx}{x(ax+b)} = \frac{1}{b} \log_e \frac{x}{ax+b}$

45. $\int \frac{dx}{x^2(ax+b)} = -\frac{1}{bx} + \frac{a}{b^2} \log_e \frac{ax+b}{x}$

46. $\int \frac{dx}{x(ax+b)^2} = \frac{1}{b(ax+b)} - \frac{1}{b^2} \log_e \frac{ax+b}{x}$

47. $\int \frac{dx}{x^2(ax+b)^2} = -\frac{b+2ax}{b^2x(ax+b)} + \frac{2a}{b^3} \log_e \frac{ax+b}{x}$

48. $\int \frac{dx}{x\sqrt{ax+b}} = \frac{1}{\sqrt{b}} \log_e \frac{\sqrt{ax+b} - \sqrt{b}}{\sqrt{ax+b} + \sqrt{b}} \quad (b \text{ positive})$

49. $\int \frac{dx}{x\sqrt{ax+b}} = \frac{2}{\sqrt{-b}} \tan^{-1} \sqrt{\frac{ax+b}{-b}} \quad (b \text{ negative})$

50. $\int \frac{\sqrt{ax+b}}{x} dx = 2\sqrt{ax+b} + \sqrt{b} \log_e \frac{\sqrt{ax+b} - \sqrt{b}}{\sqrt{ax+b} + \sqrt{b}} \quad (b \text{ positive})$

51. $\int \frac{\sqrt{ax+b}}{x} dx = 2\sqrt{ax+b} - 2\sqrt{-b} \tan^{-1} \sqrt{\frac{ax+b}{-b}} \quad (b \text{ negative})$

52. $\int \frac{dx}{x^2\sqrt{ax+b}} = -\frac{\sqrt{ax+b}}{bx} - \frac{a}{2b\sqrt{b}} \log_e \frac{\sqrt{ax+b} - \sqrt{b}}{\sqrt{ax+b} + \sqrt{b}} \quad (b \text{ positive})$

53. $\int \frac{dx}{x^2\sqrt{ax+b}} = -\frac{\sqrt{ax+b}}{bx} - \frac{a}{b\sqrt{-b}} \tan^{-1} \sqrt{\frac{ax+b}{-b}} \quad (b \text{ negative})$

54. $\int \frac{ax+b}{fx+g} dx = \frac{ax}{f} + \frac{bf - cg}{f^2} \log_e(fx+g)$

(*Continues*)

Table 18 (*Continued*)

Integrals Involving $(ax + b)$ (Continued)

55. $\int \frac{dx}{(ax+b)(fx+g)} = \frac{1}{bf-ag} \log_e \left(\frac{fx+g}{ax+b}\right) \quad (ag \neq bf)$

56. $\int \frac{x\,dx}{(ax+b)(fx+g)} = \frac{1}{bf-ag} \left[\frac{b}{a} \log_e(ax+b) - \frac{g}{f} \log_e(fx+g)\right] \quad (ag \neq bf)$

57. $\int \frac{dx}{(ax+b)^2(fx+g)} = \frac{1}{bf-ag} \left(\frac{1}{ax+b} + \frac{f}{bf-ag} \log_e \frac{fx+g}{ax+b}\right) \quad (ag \neq bf)$

Integrals Involving $ax^n + b$

58. $\int (ax^2+b)^n x\,dx = \frac{1}{2a} \frac{(ax^2+b)^{n+1}}{n+1} \quad (n \neq -1)$

59. $\int \frac{dx}{ax^2+b} = \frac{1}{\sqrt{ab}} \tan^{-1}\left(x\sqrt{\frac{a}{b}}\right) \quad$ (a and b positive)

60. $\int \frac{dx}{ax^2+b} = \frac{1}{2\sqrt{-ab}} \log_e \frac{x\sqrt{a}-\sqrt{-b}}{x\sqrt{a}+\sqrt{-b}} \quad$ (a positive, b negative)

$= \frac{1}{2\sqrt{-ab}} \log_e \frac{\sqrt{b}+x\sqrt{-a}}{\sqrt{b}-x\sqrt{-a}} \quad$ (a negative, b positive)

61. $\int \frac{dx}{x(ax^2+b)} = \frac{1}{2b} \log_e \frac{x^2}{ax^2+b}$

62. $\int \frac{dx}{(ax^2+b)^n} = \frac{1}{2(n-1)b} \frac{x}{(ax^2+b)^{n-1}} + \frac{2n-3}{2(n-1)b} \int \frac{dx}{(ax^2+b)^{n-1}} \quad$ (n integer > 1)

63. $\int \frac{x^2 dx}{ax^2+b} = \frac{x}{a} - \frac{b}{a} \int \frac{dx}{ax^2+b}$

64. $\int \frac{x^2\,dx}{(ax^2+b)^n} = \frac{1}{2(n-1)a} \frac{x}{(ax^2+b)^{n-1}} + \frac{1}{2(n-1)a} \int \frac{dx}{(ax^2+b)^{n-1}} \quad$ (n integer > 1)

65. $\int \frac{dx}{x^2(ax^2+b)^n} = \frac{1}{b} \int \frac{dx}{x^2(ax^2+b)^{n-1}} - \frac{a}{b} \int \frac{dx}{(ax^2+b)^n} \quad$ ($n =$ positive integer)

66. $\int \sqrt{ax^2+b}\,dx = \frac{x}{2}\sqrt{ax^2+b} + \frac{b}{2\sqrt{a}} \log_e \frac{x\sqrt{a}+\sqrt{ax^2+b}}{\sqrt{b}} \quad$ (a positive)

67. $\int \sqrt{ax^2+b}\,dx = \frac{x}{2}\sqrt{ax^2+b} + \frac{b}{2\sqrt{-a}} \sin^{-1}\left(x\sqrt{-\frac{a}{b}}\right) \quad$ (a negative)

68. $\int \frac{dx}{\sqrt{ax^2+b}} = \frac{1}{\sqrt{a}} \log_e(x\sqrt{a} + \sqrt{ax^2+b})_n \quad$ (a positive)

69. $\int \frac{dx}{\sqrt{ax^2+b}} = \frac{1}{\sqrt{-a}} \sin^{-1}\left(x\sqrt{-\frac{a}{b}}\right) \quad$ (a negative)

70. $\int \frac{x\,dx}{\sqrt{ax^2+b}} = \frac{1}{a}\sqrt{ax^2+b}$

71. $\int \frac{\sqrt{ax^2+b}}{x} dx = \sqrt{ax^2+b} + \sqrt{b} \log_e \frac{\sqrt{ax^2+b}-\sqrt{b}}{x} \quad$ (b positive)

72. $\int \frac{\sqrt{ax^2+b}}{x} dx = \sqrt{ax^2+b} - \sqrt{-b} \tan^{-1} \frac{\sqrt{ax^2+b}}{\sqrt{-b}} \quad$ (b negative)

73. $\int x\sqrt{ax^2+b}\,dx = \frac{1}{3a}(ax^2+b)^{3/2}$

Table 18 (*Continued*)

Integrals Involving $(ax^n + b)$ (Continued)

74. $$\int x^2\sqrt{ax^2+b}\,dx = \frac{x}{4a}(ax^2+b)^{3/2} - \frac{bx}{8a}\sqrt{ax^2+b} - \frac{b^2}{8a\sqrt{a}}\log_e(x\sqrt{a}+\sqrt{ax^2+b}) \quad (a \text{ positive})$$

75. $$\int x^2\sqrt{ax^2+b}\,dx = \frac{x}{4a}(ax^2+b)^{3/2} - \frac{bx}{8a}\sqrt{ax^2+b} - \frac{b^2}{8a\sqrt{-a}}\sin^{-1}\left(x\sqrt{\frac{-a}{b}}\right) \quad (a \text{ negative})$$

76. $$\int \frac{dx}{x\sqrt{ax^2+b}} = \frac{1}{\sqrt{b}}\log_e\frac{\sqrt{ax^2+b}-\sqrt{b}}{x} \quad (b \text{ positive})$$

77. $$\int \frac{dx}{x\sqrt{ax^2+b}} = \frac{1}{\sqrt{-b}}\sec^{-1}\left(x\sqrt{-\frac{a}{b}}\right) \quad (b \text{ negative})$$

78. $$\int \frac{x^2\,dx}{\sqrt{ax^2+b}} = \frac{x}{2a}\sqrt{ax^2+b} - \frac{b}{2a\sqrt{a}}\log_e(x\sqrt{a}+\sqrt{ax^2+b}) \quad (a \text{ positive})$$

79. $$\int \frac{x^2\,dx}{\sqrt{ax^2+b}} = \frac{x}{2a}\sqrt{ax^2+b} - \frac{b}{2a\sqrt{-a}}\sin^{-1}\left(x\sqrt{-\frac{a}{b}}\right) \quad (a \text{ negative})$$

80. $$\int \frac{\sqrt{ax^2+b}}{x^2}dx = -\frac{\sqrt{ax^2+b}}{x} + \sqrt{a}\log_e(x\sqrt{a}+\sqrt{ax^2+b}) \quad (a \text{ positive})$$

81. $$\int \frac{\sqrt{ax^2+b}}{x^2}dx = -\frac{\sqrt{ax^2+b}}{x} - \sqrt{-a}\sin^{-1}\left(x\sqrt{-\frac{a}{b}}\right) \quad (a \text{ negative})$$

82. $$\int \frac{dx}{x(ax^n+b)} = \frac{1}{bn}\log_e\frac{x^n}{ax^n+b}$$

83. $$\int \frac{dx}{x\sqrt{ax^n+b}} = \frac{1}{n\sqrt{b}}\log_e\frac{\sqrt{ax^n+b}-\sqrt{b}}{\sqrt{ax^n+b}+\sqrt{b}} \quad (b \text{ positive})$$

84. $$\int \frac{dx}{x\sqrt{ax^n+b}} = \frac{2}{n\sqrt{-b}}\sec^{-1}\sqrt{-\frac{ax^n}{b}} \quad (b \text{ negative})$$

Integrals Involving $ax^2 + bx + d$

85. $$\int \frac{dx}{ax^2+bx+d} = \frac{1}{\sqrt{b^2-4ad}}\log_e\frac{2ax+b-\sqrt{b^2-4ad}}{2ax+b+\sqrt{b^2-4ad}} \quad (b^2 > 4ad)$$

86. $$\int \frac{dx}{ax^2+bx+d} = \frac{2}{\sqrt{4ad-b^2}}\tan^{-1}\frac{2ax+b}{\sqrt{4ad-b^2}} \quad (b^2 < 4ad)$$

87. $$\int \frac{dx}{ax^2+bx+d} = -\frac{2}{2ax+b} \quad (b^2 = 4ad)$$

88. $$\int \frac{dx}{\sqrt{ax^2+bx+d}} = \frac{1}{\sqrt{a}}\log_e\left(2ax+b+2\sqrt{a(ax^2+bx+d)}\right) \quad (a \text{ positive})$$

89. $$\int \frac{dx}{\sqrt{ax^2+bx+d}} = \frac{1}{\sqrt{-a}}\sin^{-1}\frac{-2ax-b}{\sqrt{b^2-4ad}} \quad (a \text{ negative})$$

90. $$\int \frac{x\,dx}{ax^2+bx+d} = \frac{1}{2a}\log_e(ax^2+bx+d) - \frac{b}{2a}\int\frac{dx}{ax^2+bx+d}$$

91. $$\int \frac{x\,dx}{\sqrt{ax^2+bx+d}} = \frac{\sqrt{ax^2+bx+d}}{a} - \frac{b}{2a}\int\frac{dx}{\sqrt{ax^2+bx+d}}$$

92. $$\int \frac{dx}{x\sqrt{ax^2+bx+d}} = -\frac{1}{\sqrt{d}}\log_e\left(\frac{\sqrt{ax^2+bx+d}+\sqrt{d}}{x} + \frac{b}{2\sqrt{d}}\right) \quad (d \text{ positive})$$

(*Continues*)

Table 18 (*Continued*)

93. $\int \frac{dx}{x\sqrt{ax^2+bx+d}} = \frac{1}{\sqrt{-d}} \sin^{-1} \frac{bx+2d}{x\sqrt{b^2-4ad}}$ (d negative)

94. $\int \frac{dx}{x\sqrt{ax^2+bx}} = -\frac{2}{bx}\sqrt{ax^2+bx}$

95. $\int \sqrt{ax^2+bx+d}\, dx = \frac{2ax+b}{4a}\sqrt{ax^2+bx+d} + \frac{4ad-b^2}{8a}\int \frac{dx}{\sqrt{ax^2+bx+d}}$

96. $\int x\sqrt{ax^2+bx+d}\, dx = \frac{(ax^2+bx+d)^{3/2}}{3a} - \frac{b}{2a}\int \sqrt{ax^2+bx+d}\, dx$

Integrals Involving $\sin^n ax$

97. $\int \sin^3 ax\, dx = -\frac{1}{a}\cos ax + \frac{1}{3a}\cos^3 ax$

98. $\int \sin^4 ax\, dx = \frac{3}{8}x - \frac{1}{4a}\sin 2ax + \frac{1}{32a}\sin 4ax$

99. $\int \sin^n ax\, dx = -\frac{\sin^{n-1} ax \cos ax}{na} + \frac{n-1}{n}\int \sin^{n-2} ax\, dx$ (n = positive integer)

100. $\int x \sin ax\, dx = \frac{\sin ax}{a^2} - \frac{x\cos ax}{a}$

101. $\int x^2 \sin ax\, dx = \frac{2x}{a^2}\sin ax - \left(\frac{x^2}{a} - \frac{2}{a^3}\right)\cos ax$

102. $\int x^3 \sin ax\, dx = \left(\frac{3x^2}{a^2} - \frac{6}{a^4}\right)\sin ax - \left(\frac{x^3}{a} - \frac{6x}{a^3}\right)\cos ax$

103. $\int x^n \sin ax\, dx = -\frac{x^n}{a}\cos ax + \frac{n}{a}\int x^{n-1}\cos ax\, dx$ ($n > 0$)

104. $\int \frac{\sin ax}{x^n} dx = -\frac{1}{n-1}\frac{\sin ax}{x^{n-1}} + \frac{a}{n-1}\int \frac{\cos ax}{x^n-1} dx$

105. $\int \frac{dx}{\sin^n ax} = -\frac{1}{a(n-1)}\frac{\cos ax}{\sin^{n-1} ax} + \frac{n-2}{n-1}\int \frac{dx}{\sin^{n-2} ax}$ (n integer > 1)

106. $\int \frac{x\, dx}{\sin^2 ax} = -\frac{x}{a}\cot ax + \frac{1}{a^2}\log_e \sin ax$

107. $\int \frac{dx}{1+\sin ax} = -\frac{1}{a}\tan\left(\frac{\pi}{4} - \frac{ax}{2}\right)$

108. $\int \frac{dx}{1-\sin ax} = \frac{1}{a}\cot\left(\frac{\pi}{4} - \frac{ax}{2}\right)$

109. $\int \frac{x\, dx}{1+\sin ax} = -\frac{x}{a}\tan\left(\frac{\pi}{4} - \frac{ax}{2}\right) + \frac{2}{a^2}\log_e \cos\left(\frac{\pi}{4} - \frac{ax}{2}\right)$

110. $\int \frac{x\, dx}{1-\sin ax} = \frac{x}{a}\cot\left(\frac{\pi}{4} - \frac{ax}{2}\right) + \frac{2}{a^2}\log_e \sin\left(\frac{\pi}{4} - \frac{ax}{2}\right)$

111. $\int \frac{dx}{b+d\sin ax} = \frac{-2}{a\sqrt{b^2-d^2}}\tan^{-1}\left[\sqrt{\frac{b-d}{b+d}}\tan\left(\frac{\pi}{4} - \frac{ax}{2}\right)\right]$ ($b^2 > d^2$)

112. $\int \frac{dx}{b+d\sin ax} = \frac{-1}{a\sqrt{d^2-b^2}}\log_e \frac{d+b\sin ax+\sqrt{d^2-b^2}\cos ax}{b+d\sin ax}$ ($d^2 > b^2$)

113. $\int \sin ax \sin bx\, dx = \frac{\sin(a-b)x}{2(a-b)} - \frac{\sin(a+b)x}{2(a+b)}$ ($a^2 \neq b^2$)

Integrals Involving $\cos^n ax$

114. $\int \cos^3 ax\, dx = \frac{1}{a}\sin ax - \frac{1}{3a}\sin^3 ax$

115. $\int \cos^4 ax\, dx = \frac{3}{8}x + \frac{1}{4a}\sin 2ax + \frac{1}{32a}\sin 4ax$

Table 18 (*Continued*)

Integrals Involving $\cos^n ax$ *(Continued)*

116. $\int \cos^n ax\,dx = \frac{\cos^{n-1} ax \sin ax}{na} + \frac{n-1}{n}\int \cos^{n-2} ax\,dx \quad (n = \text{positive integer})$

117. $\int x\cos ax\,dx = \frac{\cos\ ax}{a^2} + \frac{x\sin ax}{a}$

118. $\int x^2\cos ax\,dx = \frac{2x}{a^2}\cos ax + \left(\frac{x^2}{a} - \frac{2}{a^3}\right)\sin ax$

119. $\int x^3\cos ax\,dx = \left(\frac{3x^2}{a^2} - \frac{6}{a^4}\right)\cos ax + \left(\frac{x^3}{a} - \frac{6x}{a^3}\right)\sin ax$

120. $\int x^n\cos ax\,dx = \frac{x^n\sin ax}{a} - \frac{n}{a}\int x^{n-1}\sin ax\,dx \quad (n > 0)$

121. $\int \frac{\cos ax}{x^n}dx = -\frac{1}{n-1}\frac{\cos ax}{x^{n-1}} - \frac{a}{n-1}\int \frac{\sin ax}{x^{n-1}}dx$

122. $\int \frac{dx}{\cos^n ax} = \frac{1}{a(n-1)}\frac{\sin ax}{\cos^{n-1} ax} + \frac{n-2}{n-1}\int \frac{dx}{\cos^{n-2} ax} \quad (n \text{ integer} > 1)$

123. $\int \frac{xdx}{\cos^2 ax} = \frac{x}{a}\tan ax + \frac{1}{a^2}\log_e \cos ax$

124. $\int \frac{dx}{1+\cos ax} = \frac{1}{a}\tan\frac{ax}{2}$

125. $\int \frac{dx}{1-\cos ax} = -\frac{1}{a}\cot\frac{ax}{2}$

126. $\int \frac{x\,dx}{1+\cos ax} = \frac{x}{a}\tan\frac{ax}{2} + \frac{2}{a^2}\log_e \cos\frac{ax}{2}$

127. $\int \frac{x\,dx}{1-\cos ax} = -\frac{x}{a}\cot\frac{ax}{2} + \frac{2}{a^2}\log_e \sin\frac{ax}{2}$

128. $\int \frac{dx}{b+d\cos ax} = \frac{2}{a\sqrt{b^2-d^2}}\tan^{-1}\left(\sqrt{\frac{b-d}{b+d}}\tan\frac{ax}{2}\right) \quad (b^2 > d^2)$

129. $\int \frac{dx}{b+d\cos ax} = \frac{1}{a\sqrt{d^2-b^2}}\log_e \frac{d+b\cos ax+\sqrt{d^2-b^2}\sin ax}{b+d\cos ax} \quad (d^2 > b^2)$

130. $\int \cos ax\cos bx\,dx = \frac{\sin(a-b)x}{2(a-b)} + \frac{\sin(a+b)\,x}{2(a+b)} \quad (a^2 \neq b^2)$

Integrals Involving $\sin^n ax, \cos^n ax$

131. $\int \sin ax\cos bx\,dx = -\frac{1}{2}\left[\frac{\cos(a-b)x}{a-b} + \frac{\cos(a+b)x}{a+b}\right] \quad (a^2 \neq b^2)$

132. $\int \sin^2 ax\cos^2 ax\,dx = \frac{x}{8} - \frac{\sin 4ax}{32a}$

133. $\int \sin^n ax\cos ax\,dx = \frac{1}{a(n+1)}\sin^{n+1} ax \quad (n \neq -1)$

134. $\int \sin ax\cos^n ax\,dx = -\frac{1}{a(n+1)}\cos^{n+1} ax \quad (n \neq -1)$

135. $\int \sin^n ax\cos^m ax\,dx = -\frac{\sin^{n-1} ax\cos^{m+1} ax}{a(n+m)} + \frac{n-1}{n+m}\int \sin^{n-2} ax\cos^m ax\,dx \quad (m,\ n \text{ pos})$

136. $\int \frac{\sin^n ax}{\cos^m ax}dx = \frac{\sin^{n+1} ax}{a(m-1)\cos^{m-1} ax} - \frac{n-m+2}{m-1}\int \frac{\sin^n ax}{\cos^{m-2} ax}dx \quad (m,\ n \text{ pos},\ m \neq 1)$

137. $\int \frac{\cos^m ax}{\sin^n\ ax}dx = \frac{-\cos^{m+1} ax}{a(n-1)\sin^{n-1} ax} + \frac{n-m-2}{n-1}\int \frac{\cos^m ax}{\sin^{n-2} ax}dx \quad (m, n \text{ pos}, n \neq 1)$

(*Continues*)

Table 18 (*Continued*)

Integrals Involving $\sin^n ax, \cos^n ax$ *(Continued)*

138. $\int \frac{dx}{\sin ax \cos ax} = \frac{1}{a} \log_e \tan ax$

139. $\int \frac{dx}{b \sin ax + d \cos ax} = \frac{1}{a\sqrt{b^2+d^2}} \log_e \tan \frac{1}{2}\left(ax + \tan^{-1} \frac{d}{b}\right)$

140. $\int \frac{\sin ax}{b + d \cos ax} dx = -\frac{1}{ad} \log_e(b + d \cos ax)$

141. $\int \frac{\cos ax}{b + d \sin ax} dx = \frac{1}{ad} \log_e(b + d \sin ax)$

Integrals Involving $\tan^n ax, \cot^n ax, \sec^n ax, \csc^n ax$

142. $\int \tan^n ax\, dx = \frac{1}{a(n-1)} \tan^{n-1} ax - \int \tan^{n-2} ax\, dx \quad (n \text{ integer} > 1)$

143. $\int \cot^n ax\, dx = -\frac{1}{a(n-1)} \cot^{n-1} ax - \int \cot^{n-2} ax\, dx \quad (n \text{ integer} > 1)$

144. $\int \sec^n ax\, dx = \frac{1}{a(n-1)} \frac{\sin ax}{\cos^{n-1} ax} + \frac{n-2}{n-1} \int \sec^{n-2} ax\, dx \quad (n \text{ integer} > 1)$

145. $\int \csc^n ax\, dx = -\frac{1}{a(n-1)} \frac{\cos ax}{\sin^{n-1} ax} + \frac{n-2}{n-1} \int \csc^{n-2} ax\, dx \quad (n \text{ integer} > 1)$

146. $\int \frac{dx}{b + d \tan ax} = \frac{1}{b^2+d^2}\left[bx + \frac{d}{a} \log_e(b \cos ax + d \sin ax)\right]$

147. $\int \frac{dx}{\sqrt{b + d \tan^2 ax}} = \frac{1}{a\sqrt{b-d}} \sin^{-1}\left[\sqrt{\frac{b-d}{b}} \sin ax\right] \quad (b \text{ pos}, \ b^2 > d^2)$

148. $\int \tan ax \sec ax\, dx = \frac{1}{a} \sec ax$

149. $\int \tan^n ax \sec^2 ax\, dx = \frac{1}{a(n+1)} \tan^{n+1} ax \quad (n \neq -1)$

150. $\int \frac{\sec^2 ax\, dx}{\tan ax} = \frac{1}{a} \log_e \tan ax$

151. $\int \cot ax \csc ax\, dx = -\frac{1}{a} \csc ax$

152. $\int \cot^n ax \csc^2 ax\, dx = -\frac{1}{a(n+1)} \cot^{n+1} ax \quad (n \neq -1)$

153. $\int \frac{\csc^2 ax}{\cot ax} dx = -\frac{1}{a} \log_e \cot ax$

Integrals Involving $b^{ax}, e^{ax}, \sin bx, \cos bx$

154. $\int xb^{ax} dx = \frac{xb^{ax}}{a \log_e b} - \frac{b^{ax}}{a^2(\log_e b)^2}$

155. $\int xe^{ax} dx = \frac{e^{ax}}{a^2}(ax - 1)$

156. $\int x^n b^{ax} dx = \frac{x^n b^{ax}}{a \log_e b} - \frac{n}{a \log_e b} \int x^{n-1} b^{ax} dx \quad (n \text{ positive})$

157. $\int x^n e^{ax} dx = \frac{1}{a} x^n e^{ax} - \frac{n}{a} \int x^{n-1} e^{ax} dx \quad (n \text{ positive})$

158. $\int \frac{dx}{b + de^{ax}} = \frac{1}{ab}[ax - \log_e(b + de^{ax})]$

Table 18 (*Continued*)

Integrals Involving $b^{ax}, e^{ax}, \sin bx, \cos bx$ (Continued)

159. $\int \frac{e^{ax}\,dx}{b+de^{ax}} = \frac{1}{ad}\log_e(b+de^{ax})$

160. $\int \frac{dx}{be^{ax}+de^{-ax}} = \frac{1}{a\sqrt{bd}}\tan^{-1}\left(e^{ax}\sqrt{\frac{b}{d}}\right)$ (b and d positive)

161. $\int \frac{e^{ax}}{x}dx = \log_e x + ax + \frac{(ax)^2}{2\cdot 2!} + \frac{(ax)^3}{3\cdot 3!} + \cdots$

162. $\int \frac{e^{ax}}{x^n}dx = \frac{1}{n-1}\left(-\frac{e^{ax}}{x^{n-1}} + a\int \frac{e^{ax}}{x^{n-1}}dx\right)$ (n integer > 1)

163. $\int e^{ax}\sin bx\,dx = \frac{e^{ax}}{a^2+b^2}(a\sin bx - b\cos bx)$

164. $\int e^{ax}\cos bx\,dx = \frac{e^{ax}}{a^2+b^2}(a\cos bx + b\sin bx)$

165. $\int xe^{ax}\sin bx\,dx = \frac{xe^{ax}}{a^2+b^2}(a\sin bx - b\cos bx) - \frac{e^{ax}}{(a^2+b^2)^2}[(a^2-b^2)\sin bx - 2ab\cos bx]$

166. $\int xe^{ax}\cos bx\,dx = \frac{xe^{ax}}{a^2+b^2}(a\cos bx + b\sin bx) - \frac{e^{ax}}{(a^2+b^2)^2}[(a^2-b^2)\cos bx + 2ab\sin bx]$

Integrals Involving $\log_e ax$

167. $\int \log_e ax\,dx = x\log_e ax - x$

168. $\int (\log_e ax)^n dx = x(\log_e ax)^n - n(\log_e ax)^{n-1}dx$ (n positive)

169. $\int x^n \log_e ax\,dx = x^{n+1}\left(\frac{\log_e ax}{n+1}\right) - \frac{1}{(n+1)^2}$ ($n \neq -1$)

170. $\int \frac{(\log_e ax)^n}{x}dx = \frac{(\log_e ax)^{n+1}}{n+1}$ ($n \neq -1$)

171. $\int \frac{dx}{x\log_e ax} = \log_e(\log_e x)$

172. $\int \frac{dx}{\log_e ax} = \frac{1}{a}\left[\log_e(\log_e ax) + \log_e ax + \frac{(\log_e ax)^2}{2\cdot 2!} + \cdots\right]$

173. $\int x^m(\log_e ax)^n dx = \frac{x^{m+1}(\log_e ax)^n}{m+1} - \frac{n}{m+1}\int x^m(\log_e ax)^{n-1}dx$ ($m,\ n \neq 1$)

174. $\int \frac{x^m dx}{(\log_e ax)^n} = -\frac{x^{m+1}}{(n-1)(\log_e ax)^{n-1}} + \frac{m+1}{n-1}\int \frac{x^m dx}{(\log_e ax)^{n-1}}$

Some Definite Integrals

1. $\int_0^a \sqrt{a^2-x^2}\,dx = \frac{\pi a^2}{4}$

2. $\int_0^a \sqrt{2ax-x^2}\,dx = \frac{\pi a^2}{4}$

(*Continues*)

Table 18 (*Continued*)

Some Definite Integrals (Continued)

3. $\int_0^\infty \frac{dx}{a+bx^2} = \frac{\pi}{2\sqrt{ab}}$ (*a* and *b* positive)
4. $\int_0^{\sqrt{a/b}} \frac{dx}{a+bx^2}\,dx = \int_{\sqrt{a/b}}^\infty \frac{dx}{a+bx^2} = \frac{\pi}{4\sqrt{ab}}$ (*a* and *b* positive)
5. $\int_0^{\sqrt{a/b}} \frac{dx}{\sqrt{a-bx^2}} = \frac{\pi}{2\sqrt{b}}$ (*a* and *b* positive)
6. $\int_0^\infty \frac{\sin bx}{x}\,dx = \begin{cases} \frac{\pi}{2} & (b>0) \\ 0 & (b=0) \\ -\frac{\pi}{2} & (b<0) \end{cases}$
7. $\int_0^\infty \frac{\tan\,x}{x}\,dx = \frac{\pi}{2}$
8. $\int_0^{\pi/2} \sin^{2n+1}\,x\,dx = \int_0^{\pi/2} \cos^{2n+1}\,x\,dx = \frac{2\cdot 4\cdot 6\cdots 2n}{3\cdot 5\cdot 7\cdots(2n+1)}$ $(n>0)$
9. $\int_0^{\pi/2} \sin^{2n}\,x\,dx = \int_0^{\pi/2} \cos^{2n}\,x\,dx = \frac{1\cdot 3\cdot 5\cdots(2n-1)}{2\cdot 4\cdot 6\cdots 2n}\cdot\frac{\pi}{2}$ $(n>0)$
10. $\int_0^\pi \sin\,ax\,\sin\,bx\,dx = \int_0^\pi \cos ax\cos bx\,dx = 0$ $(a \neq b)$
11. $\int_0^\pi \sin^2 ax\,dx = \int_0^\pi \cos^2 ax\,dx = \frac{\pi}{2}$
12. $\int_0^{\pi/2} \log_e \cos\,x\,dx = \int_0^{\pi/2} \log_e \sin\,x\,dx = -\frac{\pi}{2}\log_e 2$
13. $\int_0^\infty e^{-ax^2}\,dx = \frac{1}{2}\sqrt{\frac{\pi}{a}}$
14. $\int_0^\infty x^n e^{-ax}\,dx = \frac{n!}{a^{n+1}}$ $(a>0, n=1,2,3,\ldots)$
15. $\int_0^1 \frac{\log_e\,x}{1-x}\,dx = -\frac{\pi^2}{6}$
16. $\int_0^1 \frac{\log_e\,x}{1+x}\,dx = -\frac{\pi^2}{12}$
17. $\int_0^1 \frac{\log_e\,x}{1-x^2}\,dx = \frac{\pi^2}{8}$

Table 19 Haversines[a]

θ°	Value	Log	θ°	Value	Log	θ°	Value	Log	θ°	Value	Log
0	0.00000	—	**10**	0.00760	0.88059	**20**	0.03015	0.47934	**30**	0.06699	0.82599
1	0.00008	0.88168	11	0.00919	0.96315	21	0.03321	0.52127	31	0.07142	0.85380
2	0.00030	0.48371	12	0.01093	0.03847	22	0.03641	0.56120	32	0.07598	0.88068
3	0.00069	0.83584	13	0.01281	0.10772	23	0.03975	0.59931	33	0.08066	0.90668
4	0.00122	0.08564	14	0.01485	0.17179	24	0.04323	0.63576	34	0.08548	0.93187
5	0.00190	0.27936	15	0.01704	0.23140	25	0.04685	0.67067	35	0.09042	0.95628
6	0.00274	0.43760	16	0.01937	0.28711	26	0.05060	0.70418	36	0.09549	0.97996
7	0.00373	0.57135	17	0.02185	0.33940	27	0.05450	0.73637	37	0.10068	0.00295
8	0.00487	0.68717	18	0.02447	0.38867	28	0.05853	0.76735	38	0.10599	0.02528
9	0.00616	0.78929	19	0.02724	0.43522	29	0.06269	0.79720	39	0.11143	0.04699

Table 19 (*Continued*)

θ°	Value	Log	θ°	Value	Log	θ°	Value	Log	θ°	Value	Log
40	0.11698	0.06810	**80**	0.41318	0.61613	**120**	0.75000	0.87506	**160**	0.96985	0.98670
41	0.12265	0.08865	81	0.42178	0.62509	121	0.75752	0.87939	161	0.97276	0.98801
42	0.12843	0.10866	82	0.43041	0.63389	122	0.76496	0.88364	162	0.97553	0.98924
43	0.13432	0.12815	83	0.43907	0.64253	123	0.77232	0.88780	163	0.97815	0.99041
44	0.14033	0.14715	84	0.44774	0.65102	124	0.77960	0.89187	164	0.98063	0.99151
45	0.14645	0.16568	85	0.45642	0.65937	125	0.78679	0.89586	165	0.98296	0.99254
46	0.15267	0.18376	86	0.46512	0.66757	126	0.79389	0.89976	166	0.98515	0.99350
47	0.15900	0.20140	87	0.47383	0.67562	127	0.80091	0.90358	167	0.98719	0.99440
48	0.16543	0.21863	88	0.48255	0.68354	128	0.80783	0.90732	168	0.98907	0.99523
49	0.17197	0.23545	89	0.49127	0.69132	129	0.81466	0.91098	169	0.99081	0.99599
50	0.17861	0.25190	**90**	0.50000	0.69897	**130**	0.82139	0.91455	**170**	0.99240	0.99669
51	0.18534	0.26797	91	0.50873	0.70648	131	0.82803	0.91805	171	0.99384	0.99732
52	0.19217	0.28368	92	0.51745	0.71387	132	0.83457	0.92146	172	0.99513	0.99788
53	0.19909	0.29905	93	0.52617	0.72112	133	0.84100	0.92480	173	0.99627	0.99838
54	0.20611	0.31409	94	0.53488	0.72825	134	0.84733	0.92805	174	0.99726	0.99881
55	0.21321	0.32281	95	0.54358	0.73526	135	0.85355	0.93123	175	0.99810	0.99917
56	0.22040	0.34322	96	0.55226	0.74215	136	0.85967	0.93433	176	0.99878	0.99947
57	0.22768	0.35733	97	0.56093	0.74891	137	0.86568	0.93736	177	0.99931	0.99970
58	0.23504	0.37114	98	0.56959	0.75556	138	0.87157	0.94030	178	0.99970	0.99987
59	0.24248	0.38468	99	0.57822	0.76209	139	0.87735	0.94318	179	0.99992	0.99997
60	0.25000	0.39794	**100**	0.58682	0.76851	**140**	0.88302	0.94597	**180**	1.00000	0.00000
61	0.25760	0.41094	101	0.59540	0.77481	141	0.88857	0.94869			
62	0.26526	0.42368	102	0.60396	0.78101	142	0.89401	0.95134			
63	0.27300	0.43617	103	0.61248	0.78709	143	0.89932	0.95391			
64	0.28081	0.44842	104	0.62096	0.79306	144	0.90451	0.95641			
65	0.28869	0.46043	105	0.62941	0.79893	145	0.90958	0.95884			
66	0.29663	0.47222	106	0.63782	0.80470	146	0.91452	0.96119			
67	0.30463	0.48378	107	0.64619	0.81036	147	0.91934	0.96347			
68	0.31270	0.49512	108	0.65451	0.81592	148	0.92402	0.96568			
69	0.32082	0.50625	109	0.66278	0.82137	149	0.92858	0.96782			
70	0.32899	0.51718	**110**	0.67101	0.82673	**150**	0.93301	0.96989			
71	0.33722	0.52791	111	0.67918	0.83199	151	0.93731	0.97188			
72	0.34549	0.53844	112	0.68730	0.83715	152	0.94147	0.97381			
73	0.35381	0.54878	113	0.69537	0.84221	153	0.94550	0.97566			
74	0.36218	0.55893	114	0.70337	0.84718	154	0.94940	0.97745			
75	0.37059	0.56889	115	0.71131	0.85206	155	0.95315	0.97016			
76	0.37904	0.57868	116	0.71919	0.85684	156	0.95677	0.98081			
77	0.38752	0.58830	117	0.72700	0.86153	157	0.96025	0.98239			
78	0.39604	0.59774	118	0.73474	0.86613	158	0.96359	0.98389			
79	0.40460	0.60702	119	0.74240	0.87064	159	0.96679	0.98533			

[a] $\text{hav}\,\theta = \frac{1}{2}\,\text{vers}\,\theta = \frac{1}{2}(1-\cos\theta) = \sin^2\frac{1}{2}\theta$
$\text{hav}(-\theta) = \text{hav}\,\theta$
$\text{hav}(180^\circ - \theta) = \text{hav}(180^\circ + \theta) = 1 - \text{hav}\,\theta$
Characteristics of the logarithms are omitted.

Table 20 Complete Elliptic Integrals[a]

$\sin^{-1} k$	K	log K	E	log E	$\sin^{-1} k$	K	log K	E	log E
0°	1.5708	0.196120	1.5708	0.196120	**5**°	1.5738	0.196947	1.5678	0.195293
1	1.5709	0.196153	1.5707	0.196087	6	1.5751	0.197312	1.5665	0.194930
2	1.5713	0.196252	1.5703	0.195988	7	1.5767	0.197743	1.5649	0.194500
3	1.5719	0.196418	1.5697	0.195822	8	1.5785	0.198241	1.5632	0.194004
4	1.5727	0.196649	1.5689	0.195591	9	1.5805	0.198806	1.5611	0.193442

(*Continues*)

Table 20 (*Continued*)

$\sin^{-1} k$	K	$\log K$	E	$\log E$	$\sin^{-1} k$	K	$\log K$	E	$\log E$
10	1.5828	0.199438	1.5589	0.192815	**50°**	1.9356	0.286811	1.3055	0.115790
11	1.5854	0.200137	1.5564	0.192121	51	1.9539	0.290895	1.2963	0.112698
12	1.5882	0.200904	1.5537	0.191362	52	1.9729	0.295101	1.2870	0.109563
13	1.5913	0.201740	1.5507	0.190537	53	1.9927	0.299435	1.2776	0.106386
14	1.5946	0.202643	1.5476	0.189646	54	2.0133	0.303901	1.2681	0.103169
15	1.5981	0.203615	1.5442	0.188690	**55**	2.0347	0.308504	1.2587	0.099915
16	1.6020	0.204657	1.5405	0.187668	56	2.0571	0.313247	1.2492	0.096626
17	1.6061	0.205768	1.5367	0.186581	57	2.0804	0.318138	1.2397	0.093303
18	1.6105	0.206948	1.5326	0.185428	58	2.1047	0.323182	1.2301	0.089950
19	1.6151	0.208200	1.5283	0.184210	59	2.1300	0.328384	1.2206	0.086569
20	1.6200	0.209522	1.5238	0.182928	**60**	2.1565	0.333753	1.2111	0.083164
21	1.6252	0.210916	1.5191	0.181580	61	2.1842	0.339295	1.2015	0.079738
22	1.6307	0.212382	1.5141	0.180168	62	2.2132	0.345020	1.1920	0.076293
23	1.6365	0.213921	1.5090	0.178691	63	2.2435	0.350936	1.1826	0.072834
24	1.6426	0.215533	1.5037	0.177150	64	2.2754	0.357053	1.1732	0.069364
25	1.6490	0.217219	1.4981	0.175545	**65**	2.3088	0.363384	1.1638	0.065889
26	1.6557	0.218981	1.4924	0.173876	66	2.3439	0.369940	1.1545	0.062412
27	1.6627	0.220818	1.4864	0.172144	67	2.3809	0.376736	1.1453	0.058937
28	1.6701	0.222732	1.4803	0.170348	68	2.4198	0.383787	1.1362	0.055472
29	1.6777	0.224723	1.4740	0.168489	69	2.4610	0.391112	1.1272	0.052020
30	1.6858	0.226793	1.4675	0.166567	**70**	2.5046	0.398730	1.1184	0.048589
31	1.6941	0.228943	1.4608	0.164583	71	2.5507	0.406665	1.1096	0.045183
32	1.7028	0.231173	1.4539	0.162537	72	2.5998	0.414943	1.1011	0.041812
33	1.7119	0.233485	1.4469	0.160429	73	2.6521	0.423596	1.0927	0.038481
34	1.7214	0.235880	1.4397	0.158261	74	2.7081	0.432660	1.0844	0.035200
35	1.7312	0.238359	1.4323	0.156031	**75**	2.7681	0.442176	1.0764	0.031976
36	1.7415	0.240923	1.4248	0.153742	76	2.8327	0.452196	1.0686	0.028819
37	1.7552	0.243575	1.4171	0.151393	77	2.9026	0.462782	1.0611	0.025740
38	1.7633	0.246315	1.4092	0.148985	78	2.9786	0.474008	1.0538	0.022749
39	1.7748	0.249146	1.4013	0.146519	79	3.0617	0.485967	1.0468	0.019858
40	1.7868	0.252068	1.3931	0.143995	**80**	3.1534	0.498777	1.0401	0.017081
41	1.7992	0.255085	1.3849	0.141414	81	3.2553	0.512591	1.0338	0.014432
42	1.8122	0.258197	1.3765	0.138778	82	3.3699	0.527613	1.0278	0.011927
43	1.8256	0.261406	1.3680	0.136086	83	3.5004	9.544120	1.0223	0.009584
44	1.8396	0.264716	1.3594	0.133340	84	3.6519	0.562514	1.0172	0.007422
45	1.8541	0.268127	1.3506	0.130541	**85**	3.8317	0.583396	1.0127	0.005465
46	1.8691	0.271644	1.3418	0.127690	86	4.0528	0.607751	1.0086	0.003740
47	1.8848	0.275267	1.3329	0.124788	87	4.3387	0.637355	1.0053	0.002278
48	1.9011	0.279001	1.3238	0.121836	88	4.7427	0.676027	1.0026	0.001121
49	1.9180	0.282848	1.3147	0.118836	89	5.4349	0.735192	1.0008	0.000326
					90	∞	∞	1.0000	0.000000

$\sin^{-1}$	k	K	$\log K$	$\sin^{-1} k$	k	K	$\log K$	$\sin^{-1} k$	k	K	$\log K$
89	**20**	5.840	0.76641	**89**	**40**	6.533	0.81511	**89**	**50**	7.226	0.85890
89	22	5.891	0.77019	89	41	6.584	0.81849	89	51	7.332	0.86522
89	24	5.946	0.77422	89	42	6.639	0.82210	89	52	7.449	0.87210
89	26	6.003	0.77837	89	43	6.696	0.82582	89	53	7.583	0.87984
89	28	6.063	0.78269	89	44	6.756	0.82969	89	54	7.737	0.88857
89	**30**	6.128	0.78732	**89**	**45**	6.821	0.83385	**89**	**55**	7.919	0.89867
89	32	6.197	0.79218	89	46	6.890	0.83822	89	56	8.143	0.91078
89	34	6.271	0.79734	89	47	6.964	0.84286	89	57	8.430	0.92583
89	36	6.351	0.80284	89	48	7.044	0.84782	89	58	8.836	0.94626
89	38	6.438	0.80875	89	49	7.131	0.85315	89	59	9.529	0.97905
								90	**0**	∞	∞

Table 21 Gamma Functions[a]

n	$\Gamma(n)$	n	$\Gamma(n)$	n	$\Gamma(n)$	n	$\Gamma(n)$
1.00	1.00000	1.25	0.90640	1.50	0.88623	1.75	0.91906
1.01	0.99433	1.26	0.90440	1.51	0.88659	1.76	0.92137
1.02	0.98884	1.27	0.90250	1.52	0.88704	1.77	0.92376
1.03	0.98355	1.28	0.90072	1.53	0.88757	1.78	0.92623
1.04	0.97844	1.29	0.89904	1.54	0.88818	1.79	0.92877
1.05	0.97350	1.30	0.89747	1.55	0.88887	1.80	0.93138
1.06	0.96874	1.31	0.89600	1.56	0.88964	1.81	0.93408
1.07	0.96415	1.32	0.89464	1.57	0.89049	1.82	0.93685
1.08	0.95973	1.33	0.89338	1.58	0.89142	1.83	0.93969
1.09	0.95546	1.34	0.89222	1.59	0.89243	1.84	0.94261
1.10	0.95135	1.35	0.89115	1.60	0.89352	1.85	0.94561
1.11	0.94739	1.36	0.89018	1.61	0.89468	1.86	0.94869
1.12	0.94359	1.37	0.88931	1.62	0.89592	1.87	0.95184
1.13	0.93993	1.38	0.88854	1.63	0.89724	1.88	0.95507
1.14	0.93642	1.39	0.88785	1.64	0.89864	1.89	0.95838
1.15	0.93304	1.40	0.88726	1.65	0.90012	1.90	0.96177
1.16	0.92980	1.41	0.88676	1.66	0.90167	1.91	0.96523
1.17	0.92670	1.42	0.88636	1.67	0.90330	1.92	0.96878
1.18	0.92373	1.43	0.88604	1.68	0.90500	1.93	0.97240
1.19	0.92088	1.44	0.88580	1.69	0.90678	1.94	0.97610
1.20	0.91817	1.45	0.88565	1.70	0.90864	1.95	0.97988
1.21	0.91558	1.46	0.88560	1.71	0.91057	1.96	0.98374
1.22	0.91311	1.47	0.88563	1.72	0.91258	1.97	0.98768
1.23	0.91075	1.48	0.88575	1.73	0.91466	1.98	0.99171
1.24	0.90852	1.49	0.88595	1.74	0.91683	1.99	0.99581
						2.00	1.00000

[a]Values of $\Gamma(n) = \int_0^\infty e^{-x}x^{n-1}\,dx$; $\Gamma(n+1) = n\Gamma(n)$.

For large positive integers, Stirling's formula gives an approximation in which the relative error decreases as n increases:

$$\Gamma(n+1) = (2\pi n)^{1/2}\left(\frac{n}{e}\right)^n$$

Source: From *CRC Standard Mathematical Tables*, Chemical Rubber Publishing Co., 12th ed., 1959. Used by permission.

Table 22 Bessel Functions

$J_0(x)$ and $J_1(x)$[a]								
x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$
0.0	1.0000	0.0000	1.5	0.5118	0.5579	3.0	−0.2601	0.3391
0.1	0.9975	0.0499	1.6	0.4554	0.5699	3.1	−0.2921	0.3009
0.2	0.9900	0.0995	1.7	0.3980	0.5778	3.2	−0.3202	0.2613
0.3	0.9776	0.1483	1.8	0.3400	0.5815	3.3	−0.3443	0.2207
0.4	0.9604	0.1960	1.9	0.2818	0.5812	3.4	−0.3643	0.1792
0.5	0.9385	0.2423	2.0	0.2239	0.5767	3.5	−0.3801	0.1374
0.6	0.9120	0.2867	2.1	0.1666	0.5683	3.6	−0.3918	0.0955
0.7	0.8812	0.3290	2.2	0.1104	0.5560	3.7	−0.3992	0.0538
0.8	0.8463	0.3668	2.3	0.0555	0.5399	3.8	−0.4026	0.0128
0.9	0.8075	0.4059	2.4	0.0025	0.5202	3.9	−0.4018	−0.0272
1.0	0.7652	0.4401	2.5	−0.0484	0.4971	4.0	−0.3971	−0.0660
1.1	0.7196	0.4709	2.6	−0.0968	0.4708	4.1	−0.3887	−0.1033
1.2	0.6711	0.4983	2.7	−0.1424	0.4416	4.2	−0.3766	−0.1386
1.3	0.6201	0.5220	2.8	−0.1850	0.4097	4.3	−0.3610	−0.1719
1.4	0.5669	0.5419	2.9	−0.2243	0.3754	4.4	−0.3423	−0.2028

(*Continues*)

Table 22 (*Continued*)

$J_0(x)$ and $J_1(x)$[a]								
x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$	x	$J_0(x)$	$J_1(x)$
4.5	−0.3205	−0.2311	6.0	0.1506	−0.2767	7.5	0.2663	0.1352
4.6	−0.2961	−0.2566	6.1	0.1773	−0.2559	7.6	0.2516	0.1592
4.7	−0.2693	−0.2791	6.2	0.2017	−0.2329	7.7	0.2346	0.1813
4.8	−0.2404	−0.2985	6.3	0.2238	−0.2081	7.8	0.2154	0.2014
4.9	−0.2097	−0.3147	6.4	0.2433	−0.1816	7.9	0.1944	0.2192
5.0	−0.1776	−0.3276	6.5	0.2601	−0.1538	8.0	0.1717	0.2346
5.1	−0.1443	−0.3371	6.6	0.2740	−0.1250	8.1	0.1475	0.2476
5.2	−0.1103	−0.3432	6.7	0.2851	−0.0953	8.2	0.1222	0.2580
5.3	−0.0758	−0.3460	6.8	0.2931	−0.0652	8.3	0.0960	0.2657
5.4	−0.0412	−0.3453	6.9	0.2981	−0.0349	8.4	0.0692	0.2708
5.5	−0.0068	−0.3414	7.0	0.3001	−0.0047	8.5	0.0419	0.2731
5.6	0.0270	−0.3343	7.1	0.2991	0.0252	8.6	0.0146	0.2728
5.7	0.0599	−0.3241	7.2	0.2951	0.0543	8.7	−0.0125	0.2697
5.8	0.0917	−0.3110	7.3	0.2882	0.0826	8.8	−0.0392	0.2641
5.9	0.1220	−0.2951	7.4	0.2786	0.1096	8.9	−0.0653	0.2559
$Y_0(x)$ and $Y_1(x)$								
x	$Y_0(x)$	$Y_1(x)$	x	$Y_0(x)$	$Y_1(x)$	x	$Y_0(x)$	$Y_1(x)$
0.0	$(-\infty)$	$(-\infty)$	2.5	0.498	0.146	5.0	−0.309	0.148
0.5	−0.445	−1.471	3.0	0.377	0.325	5.5	−0.340	−0.024
1.0	0.088	−0.781	3.5	0.189	0.410	6.0	−0.288	−0.175
1.5	0.382	−0.412	4.0	−0.017	0.398	6.5	−0.173	−0.274
2.0	0.510	−0.107	4.5	−0.195	0.301	7.0	−0.026	−0.303

[a] $J_1(x) = 0$ for $x = 0, 3.832, 7.016, 10.173, 13.324, \ldots$
$J_0(x) = 0$ for $x = 2.405, 5.520, 8.654, 11.792, \ldots$

3 STATISTICAL TABLES*

Table 23 Binomial Coefficients

n	$\binom{n}{0}$	$\binom{n}{1}$	$\binom{n}{2}$	$\binom{n}{3}$	$\binom{n}{4}$	$\binom{n}{5}$	$\binom{n}{6}$	$\binom{n}{7}$	$\binom{n}{8}$	$\binom{n}{9}$	$\binom{n}{10}$
0	1										
1	1	1									
2	1	2	1								
3	1	3	3	1							
4	1	4	6	4	1						
5	1	5	10	10	5	1					
6	1	6	15	20	15	6	1				
7	1	7	21	35	35	21	7	1			
8	1	8	28	56	70	56	28	8	1		
9	1	9	36	84	126	126	84	36	9	1	
10	1	10	45	120	210	252	210	120	45	10	1
11	1	11	55	165	330	462	462	330	165	55	11
12	1	12	66	220	495	792	924	792	495	220	66
13	1	13	78	286	715	1287	1716	1716	1287	715	286
14	1	14	91	364	1001	2002	3003	3432	3003	2002	1001
15	1	15	105	455	1365	3003	5005	6435	6435	5005	3003
16	1	16	120	560	1820	4368	8008	11440	12870	11440	8008
17	1	17	136	680	2380	6188	12376	19448	24310	24310	19448
18	1	18	153	816	3060	8568	18564	31824	43758	48620	43758
19	1	19	171	969	3876	11628	27132	50388	75582	92378	92378
20	1	20	190	1140	4845	15504	38760	77520	125970	167960	184756

$$ {}_nC_m = \binom{n}{m} = \frac{n!}{[(n-m)!m!]} = \binom{n}{n-m}, \binom{n}{0} = 1, $$

$$ (p+q)^n = p^n + \binom{n}{1} p^{n-1} q + \cdots + \binom{n}{s} p^s q^t + \cdots + q^n, \; s + t = n. $$

*Tables 23–25 from Burington, *Handbook of Math Tables and Formulas*, published by McGraw-Hill.

Probability Let p be the probability of an event e in one trial and q the probability of failure of e. The probability that, in n trials, the event e will occur exactly $n - t$ times is $\binom{n}{t} p^{n-t} q^t$. The probability that an event e will happen at least r times in n trials is $\sum_{t=0}^{t=n-r} \binom{n}{t} p^{n-t} q^t$; at most r times in n trials is $\sum_{t=n-r}^{t=n} \binom{n}{t} p^{n-t} q^t$.

In a *point binomial*, $(p+q)^n$, distribution, the mean number of favorable events is np; the mean number of unfavorable events is nq; the *standard deviation* is $\sigma = \sqrt{pqn}$; and $a_3 = (p-q)/\sigma$. The *mean deviation from the mean* MD is $\sigma\sqrt{2/\pi} = 0.7979\sigma$; the *semiquartile deviation from the mean is* $0.6745\sigma = 0.845$ MD.

The probability that a deviation of an individual measure from the average lies between $y = -a$ and $y = a$ is

$$\frac{1}{\sqrt{\pi}} \int_{y=-a}^{y=a} h e^{-h^2 y^2}\, dy = \frac{1}{\sigma\sqrt{2\pi}} \int_{y=-a}^{y=a} e^{-y^2/2\sigma^2} dy$$

$$= \frac{1}{\sqrt{2\pi}} \int_{x=-b}^{x=b} e^{-x^2/2}\, dx$$

where $x = hy\sqrt{2}$, $b = ha\sqrt{2}$, and $\sigma = 1/h\sqrt{2}$; h is called the *modulus of precision* and σ the *standard* (*quadratic mean*) *deviation*.

Table 24 Probability Functions

$\frac{1}{2}(1+\alpha) = \int_{-\infty}^{x} \Phi(x)\ dx$ = area under $\Phi(x)$ from $-\infty$ to x

$\alpha = \int_{-x}^{x} \Phi(x)\ dx$, $\quad \Phi(x) = \dfrac{1}{\sqrt{2\pi}} e^{-x^2/2}$ = normal function

$\Phi^{(2)}(x) = (x^2 - 1)$ $\quad \Phi(x)$ = second derivative of $\Phi(x)$

$\Phi^{(3)}(x) = (3x - x^3)$ $\quad \Phi(x)$ = third derivative of $\Phi(x)$

$\Phi^{(4)}(x) = (x^4 - 6x^2 + 3)$ $\quad \Phi(x)$ = fourth derivative of $\Phi(x)$

x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$	x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$
0.00	0.5000	0.3989	−0.3989	0.0000	1.1968	0.25	0.5987	0.3867	−0.3625	0.2840	1.0165
0.01	0.5040	0.3989	−0.3989	0.0120	1.1965	0.26	0.6026	0.3857	−0.3596	0.2941	1.0024
0.02	0.5080	0.3989	−0.3987	0.0239	1.1956	0.27	0.6064	0.3847	−0.3566	0.3040	0.9878
0.03	0.5120	0.3988	−0.3984	0.0359	1.1941	0.28	0.6103	0.3836	−0.3535	0.3138	0.9727
0.04	0.5160	0.3986	−0.3980	0.0478	1.1920	0.29	0.6141	0.3825	−0.3504	0.3235	0.9572
0.05	0.5199	0.3984	−0.3975	0.0597	1.1894	0.30	0.6179	0.3814	−0.3471	0.3330	0.9413
0.06	0.5239	0.3982	−0.3968	0.0716	1.1861	0.31	0.6217	0.3802	−0.3437	0.3423	0.9250
0.07	0.5279	0.3980	−0.3960	0.0834	1.1822	0.32	0.6255	0.3790	−0.3402	0.3515	0.9082
0.08	0.5319	0.3977	−0.3951	0.0952	1.1778	0.33	0.6293	0.3778	−0.3367	0.3605	0.8910
0.09	0.5359	0.3973	−0.3941	0.1070	1.1727	0.34	0.6331	0.3765	−0.3330	0.3693	0.8735
0.10	0.5398	0.3970	−0.3930	0.1187	1.1671	0.35	0.6368	0.3752	−0.3293	0.3779	0.8556
0.11	0.5438	0.3965	−0.3917	0.1303	1.1609	0.36	0.6406	0.3739	−0.3255	0.3864	0.8373
0.12	0.5478	0.3961	−0.3904	0.1419	1.1541	0.37	0.6443	0.3726	−0.3216	0.3947	0.8186
0.13	0.5517	0.3956	−0.3889	0.1534	1.1468	0.38	0.6480	0.3712	−0.3176	0.4028	0.7996
0.14	0.5557	0.3951	−0.3873	0.1648	1.1389	0.39	0.6517	0.3697	−0.3135	0.4107	0.7803
0.15	0.5596	0.3945	−0.3856	0.1762	1.1304	0.40	0.6554	0.3683	−0.3094	0.4184	0.7607
0.16	0.5636	0.3939	−0.3838	0.1874	1.1214	0.41	0.6591	0.3668	−0.3059	0.4259	0.7408
0.17	0.5675	0.3932	−0.3819	0.1986	1.1118	0.42	0.6628	0.3653	−0.3008	0.4332	0.7206
0.18	0.5714	0.3925	−0.3798	0.2097	1.1017	0.43	0.6664	0.3637	−0.2965	0.4403	0.7001
0.19	0.5753	0.3918	−0.3777	0.2206	1.0911	0.44	0.6700	0.3621	−0.2920	0.4472	0.6793
0.20	0.5793	0.3910	−0.3754	0.2315	1.0799	0.45	0.6736	0.3605	−0.2875	0.4539	0.6583
0.21	0.5832	0.3902	−0.3730	0.2422	1.0682	0.46	0.6772	0.3589	−0.2830	0.4603	0.6371
0.22	0.5871	0.3894	−0.3706	0.2529	1.0560	0.47	0.6808	0.3572	−0.2783	0.4666	0.6156
0.23	0.5910	0.3885	−0.3680	0.2634	1.0434	0.48	0.6844	0.3555	−0.2736	0.4727	0.5940
0.24	0.5948	0.3876	−0.3653	0.2737	1.0302	0.49	0.6879	0.3538	−0.2689	0.4785	0.5721

(*Continues*)

Table 24 (*Continued*)

x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$	x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$
0.50	0.6915	0.3521	−0.2641	0.4841	0.5501	0.95	0.8289	0.2541	−0.0248	0.5062	−0.4066
0.51	0.6950	0.3503	−0.2592	0.4895	0.5279	0.96	0.8315	0.2516	−0.0197	−0.521	−0.4228
0.52	0.6985	0.3485	−0.2543	0.4947	0.5056	0.97	0.8340	0.2492	−0.0147	0.4978	−0.4387
0.53	0.7019	0.3467	−0.2493	0.4996	0.4831	0.98	0.8365	0.2468	−0.0098	0.4933	−0.4541
0.54	0.7054	0.3448	−0.2443	0.5043	0.4605	0.99	0.8389	0.2444	−0.0049	0.4887	−0.4692
0.55	0.7088	0.3429	−0.2392	0.5088	0.4378	1.00	0.8413	0.2420	0.0000	0.4839	−0.4839
0.56	0.7123	0.3410	−0.2341	0.5131	0.4150	1.01	0.8438	0.2396	0.0048	0.4790	−0.4983
0.57	0.7157	0.3391	−0.2289	0.5171	0.3921	1.02	0.8461	0.2371	0.0096	0.4740	−0.5122
0.58	0.7190	0.3372	−0.2238	0.5209	0.3691	1.03	0.8485	0.2347	0.0143	0.4688	−0.5257
0.59	0.7224	0.3352	−0.2185	0.5245	0.3461	1.04	0.8508	0.2323	0.0190	0.4635	−0.5389
0.60	0.7257	0.3332	−0.2133	0.5278	0.3231	1.05	0.8531	0.2299	0.0236	0.4580	−0.5516
0.61	0.7291	0.3312	−0.2080	0.5309	0.3000	1.06	0.8554	0.2275	0.0281	0.4524	−0.5639
0.62	0.7324	0.3292	−0.2027	0.5338	0.2770	1.07	0.8577	0.2251	0.0326	0.4467	−0.5758
0.63	0.7357	0.3271	−0.1973	0.5365	0.2539	1.08	0.8599	0.2227	0.0371	0.4409	−0.5873
0.64	0.7389	0.3251	−0.1919	0.5389	0.2309	1.09	0.8621	0.2203	0.0414	0.4350	−0.5984
0.65	0.7422	0.3230	−0.1865	0.5411	0.2078	1.10	0.8643	0.2179	0.0458	0.4290	−0.6091
0.66	0.7454	0.3209	−0.1811	0.5431	0.1849	1.11	0.8665	0.2155	0.0500	0.4228	−0.6193
0.67	0.7486	0.3187	−0.1757	0.5448	0.1620	1.12	0.8686	0.2131	0.0542	0.4166	−0.6292
0.68	0.7517	0.3166	−0.1702	0.5463	0.1391	1.13	0.8708	0.2107	0.0583	0.4102	−0.6386
0.69	0.7549	0.3144	−0.1647	0.5476	0.1164	1.14	0.8729	0.2083	0.0624	0.4038	−0.6476
0.70	0.7580	0.3123	−0.1593	0.5486	0.0937	1.15	0.8749	0.2059	0.0664	0.3973	−0.6561
0.71	0.7611	0.3101	−0.1538	0.5495	0.0712	1.16	0.8770	0.2036	0.0704	0.3907	−0.6643
0.72	0.7642	0.3079	−0.1483	0.5501	0.0487	1.17	0.8790	0.2012	0.0742	0.3840	−0.6720
0.73	0.7673	0.3056	−0.1428	0.5504	0.0265	1.18	0.8810	0.1989	0.0780	0.3772	−0.6792
0.74	0.7704	0.3034	−0.1373	0.5506	0.0043	1.19	0.8830	0.1965	0.0818	0.3704	−0.6861
0.75	0.7734	0.3011	−0.1318	0.5505	−0.0176	1.20	0.8849	0.1942	0.0854	0.3635	−0.6926
0.76	0.7764	0.2989	−0.1262	0.5502	−0.0394	1.21	0.8869	0.1919	0.0890	0.3566	−0.6986
0.77	0.7794	0.2966	−0.1207	0.5497	−0.0611	1.22	0.8888	0.1919	0.0890	0.3566	−0.6986
0.78	0.7823	0.2943	−0.1153	0.5490	−0.0825	1.23	0.8907	0.1872	0.0960	0.3425	−0.7094
0.79	0.7852	0.2920	−0.1098	0.5481	−0.1037	1.24	0.8925	0.1849	0.0994	0.3354	−0.7141
0.80	0.7881	0.2897	−0.1043	0.5469	−0.1247	1.25	0.8944	0.1826	0.1027	0.3282	−0.7185
0.81	0.7910	0.2874	−0.0988	0.5456	−0.1455	1.26	0.8962	0.1804	0.1060	0.3210	−0.7224
0.82	0.7939	0.2850	−0.0934	0.5440	−0.1660	1.27	0.8980	0.1781	0.1092	0.3138	−0.7259
0.83	0.7967	0.2827	−0.0880	0.5423	−0.1862	1.28	0.8997	0.1758	0.1123	0.3065	−0.7291
0.84	0.7995	0.2803	−0.0825	0.5403	−0.2063	1.29	0.9015	0.1736	0.1153	0.2992	−0.7318
0.85	0.8023	0.2780	−0.0771	0.5381	−0.2260	1.30	0.9032	0.1714	0.1182	0.2918	−0.7341
0.86	0.8051	0.2756	−0.0718	0.5358	−0.2455	1.31	0.9049	0.1691	0.1211	0.2845	−0.7361
0.87	0.8078	0.2732	−0.0664	0.5332	−0.2646	1.32	0.9066	0.1669	0.1239	0.2771	−0.7376
0.88	0.8106	0.2709	−0.0611	0.5305	−0.2835	1.33	0.9082	0.1647	0.1267	0.2697	−0.7388
0.89	0.8133	0.2685	−0.0558	0.5276	−0.3021	1.34	0.9099	0.1626	0.1293	0.2624	−0.7395
0.90	0.8159	0.2661	−0.0506	0.5245	−0.3203	1.35	0.9115	0.1604	0.1319	0.2550	−0.7399
0.91	0.8186	0.2637	−0.0453	0.5212	−0.3383	1.36	0.9131	0.1582	0.1344	0.2476	−0.7400
0.92	0.8212	0.2613	−0.0401	0.5177	−0.3559	1.37	0.9147	0.1561	0.1369	0.2402	−0.7396
0.93	0.8238	0.2589	−0.0350	0.5140	−0.3731	1.38	0.9162	0.1539	0.1392	0.2328	−0.7389
0.94	0.8264	0.2565	−0.0299	0.5102	−0.3901	1.39	0.9177	0.1518	0.1415	0.2254	−0.7378

Table 24 (*Continued*)

x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$	x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$
1.40	0.9192	0.1497	0.1437	0.2180	−0.7364	1.85	0.9678	0.0721	0.1746	−0.0563	−0.4195
1.41	0.9207	0.1476	0.1459	0.2107	−0.7347	1.86	0.9686	0.0707	0.1740	−0.0605	−0.4095
1.42	0.9222	0.1456	0.1480	0.2033	−0.7326	1.87	0.9693	0.0694	0.1734	−0.0645	−0.3995
1.43	0.9236	0.1435	0.1500	0.1960	−0.7301	1.88	0.9699	0.0681	0.1727	−0.0685	−0.3894
1.44	0.9251	0.1415	0.1519	0.1887	−0.7274	1.89	0.9706	0.0669	0.1720	−0.0723	−0.3793
1.45	0.9265	0.1394	0.1537	0.1815	−0.7243	1.90	0.9713	0.0656	0.1713	−0.0761	−0.3693
1.46	0.9279	0.1374	0.1555	0.1742	−0.7209	1.91	0.9719	0.0644	0.1705	−0.0797	−0.3592
1.47	0.9292	0.1354	0.1572	0.1670	−0.7172	1.92	0.9726	0.0632	0.1697	−0.0832	−0.3492
1.48	0.9306	0.1344	0.1588	0.1599	−0.7132	1.93	0.9732	0.0620	0.1688	−0.0867	−0.3392
1.49	0.9319	0.1315	0.1604	0.1528	−0.7089	1.94	0.9738	0.0608	0.1679	−0.0900	−0.3292
1.50	0.9332	0.1295	0.1619	0.1457	−0.7043	1.95	0.9744	0.0596	0.1670	−0.0933	−0.3192
1.51	0.9345	0.1276	0.1633	0.1387	−0.6994	1.96	0.9750	0.0584	0.1661	−0.0964	−0.3093
1.52	0.9357	0.1257	0.1647	0.1317	−0.6942	1.97	0.9756	0.0573	0.1651	−0.0994	−0.2994
1.53	0.9370	0.1238	0.1660	0.1248	−0.6888	1.98	0.9761	0.0562	0.1641	−0.1024	−0.2895
1.54	0.9382	0.1219	0.1672	0.1180	−0.6831	1.99	0.9767	0.0551	0.1630	−0.1052	−0.2797
1.55	0.9394	0.1200	0.1683	0.1111	−0.6772	2.00	0.9772	0.0540	0.1620	−0.1080	−0.2700
1.56	0.9406	0.1182	0.1694	0.1044	−0.6710	2.01	0.9778	0.0529	0.1609	−0.1106	−0.2603
1.57	0.9418	0.1163	0.1704	0.0977	−0.6646	2.02	0.9783	0.0519	0.1598	−0.1132	−0.2506
1.58	0.9429	0.1145	0.1714	0.0911	−0.6580	2.03	0.9788	0.0508	0.1586	−0.1157	−0.2411
1.59	0.9441	0.1127	0.1722	0.0846	−0.6511	2.04	0.9793	0.0498	0.1575	−0.1180	−0.2316
1.60	0.9452	0.1109	0.1730	0.0781	−0.6441	2.05	0.9798	0.0468	0.1563	−0.1203	−0.2222
1.61	0.9463	0.1092	0.1738	0.0717	−0.6368	2.06	0.9803	0.0478	0.1550	−0.1225	−0.2129
1.62	0.9474	0.1074	0.1745	0.0654	−0.6293	2.07	0.9808	0.0468	0.1538	−0.1245	−0.2036
1.63	0.9484	0.1057	0.1751	0.0591	−0.6216	2.08	0.9812	0.0459	0.1526	−0.1265	−0.1945
1.64	0.9495	0.1040	0.1757	0.0529	−0.6138	2.09	0.9817	0.0449	0.1513	−0.1284	−0.1854
1.65	0.9505	0.1023	0.1762	0.0468	−0.6057	2.10	0.9821	0.0440	0.1500	−0.1302	−0.1765
1.66	0.9515	0.1006	0.1766	0.0408	−0.5975	2.11	0.9821	0.0440	0.1500	−0.1302	−0.1765
1.67	0.9525	0.0989	0.1770	0.0349	−0.5891	2.12	0.9830	0.0422	0.1474	−0.1336	−0.1588
1.68	0.9535	0.0973	0.1773	0.0290	−0.5806	2.13	0.9834	0.0413	0.1460	−0.1351	−0.1502
1.69	0.9545	0.0957	0.1776	0.0233	−0.5720	2.14	0.9838	0.0404	0.1446	−0.1366	−0.1416
1.70	0.9554	0.0940	0.1778	0.0176	−0.5632	2.15	0.9842	0.0395	0.1433	−0.1380	−0.1332
1.71	0.9564	0.0925	0.1779	0.0120	−0.5542	2.16	0.9846	0.0387	0.1419	−0.1393	−0.1249
1.72	0.9573	0.0909	0.1780	0.0065	−0.5452	2.17	0.9850	0.0379	0.1405	−0.1405	−0.1167
1.73	0.9582	0.0893	0.1780	0.0011	−0.5360	2.18	0.9854	0.0371	0.1391	−0.1416	−0.1086
1.74	0.9591	0.0878	0.1780	−0.0042	−0.5267	2.19	0.9857	0.0363	0.1377	−0.1426	−0.1006
1.75	0.9599	0.0863	0.1780	−0.0094	−0.5173	2.20	0.9861	0.0355	0.1362	−0.1436	−0.0927
1.76	0.9608	0.0848	0.1778	−0.0146	−0.5079	2.21	0.9864	0.0347	0.1348	−0.1445	−0.0850
1.77	0.9616	0.0833	0.1777	−0.0196	−0.4983	2.22	0.9868	0.0339	0.1333	−0.1453	−0.0774
1.78	0.9625	0.0818	0.1774	−0.0245	−0.4887	2.23	0.9871	0.0332	0.1319	−0.1460	−0.0700
1.79	0.9633	0.0804	0.1772	−0.0294	−0.4789	2.24	0.9875	0.0325	0.1304	−0.1467	−0.0626
1.80	0.9641	0.0790	0.1769	−0.0341	−0.4692	2.25	0.9878	0.0317	0.1289	−0.1473	−0.0554
1.81	0.9649	0.0775	0.1765	−0.0388	−0.4593	2.26	0.9881	0.0310	0.1275	−0.1478	−0.0484
1.82	0.9656	0.0761	0.1761	−0.0433	−0.4494	2.27	0.9884	0.0303	0.1260	−0.1483	−0.0414
1.83	0.9664	0.0748	0.1756	−0.0477	−0.4395	2.28	0.9887	0.0297	0.1245	−0.1486	−0.0346
1.84	0.9671	0.0734	0.1751	−0.0521	−0.4295	2.29	0.9890	0.0290	0.1230	−0.1490	−0.0279

(*Continues*)

Table 24 (*Continued*)

x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$	x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$
2.30	0.9893	0.0283	0.1215	−0.1492	−0.0214	2.80	0.9974	0.0079	0.0541	−0.1073	0.1379
2.31	0.9896	0.0277	0.1200	−0.1494	−0.0150	2.81	0.9975	0.0077	0.0531	−0.1059	0.1383
2.32	0.9898	0.0270	0.1185	−0.1495	−0.0088	2.82	0.9976	0.0075	0.0520	−0.1045	0.1386
2.33	0.9901	0.0264	0.1170	−0.1496	−0.0027	2.83	0.9977	0.0073	0.0510	−0.1031	0.1389
2.34	0.9904	0.0258	0.1155	−0.1496	0.0033	2.84	0.9977	0.0071	0.0500	−0.1017	0.1390
2.35	0.9906	0.0252	0.1141	−0.1495	0.0092	2.85	0.9978	0.0069	0.0490	−0.1003	0.1391
2.36	0.9909	0.0246	0.1126	−0.1494	0.0149	2.86	0.9979	0.0067	0.0480	−0.0990	0.1391
2.37	0.9911	0.0241	0.1111	−0.1492	0.0204	2.87	0.9979	0.0065	0.0470	−0.0976	0.1391
2.38	0.9913	0.0235	0.1096	−0.1490	0.0258	2.88	0.9980	0.0063	0.0460	−0.0962	0.1389
2.39	0.9916	0.0229	0.1081	−0.1487	0.0311	2.89	0.9981	0.0061	0.0451	−0.0948	0.1388
2.40	0.9918	0.0224	0.1066	−0.1483	0.0362	2.90	0.9981	0.0060	0.0441	−0.0934	0.1385
2.41	0.9920	0.0219	0.1051	−0.1480	0.0412	2.91	0.9982	0.0058	0.0432	−0.0920	0.1382
2.42	0.9922	0.0213	0.1036	−0.1475	0.0461	2.92	0.9982	0.0056	0.0423	−0.0906	0.1378
2.43	0.9925	0.0208	0.1022	−0.1470	0.0508	2.93	0.9983	0.0055	0.0414	−0.0893	0.1374
2.44	0.9927	0.0203	0.1007	−0.1465	0.0554	2.94	0.9984	0.0053	0.0405	−0.0879	0.1369
2.45	0.9929	0.0198	0.0992	−0.1459	0.0598	2.95	0.9984	0.0051	0.0396	−0.0865	0.1364
2.46	0.9931	0.0194	0.0978	−0.1453	0.0641	2.96	0.9985	0.0050	0.0388	−0.0852	0.1358
2.47	0.9932	0.0189	0.0963	−0.1446	0.0683	2.97	0.9985	0.0048	0.0379	−0.0838	0.1352
2.48	0.9934	0.0184	0.0949	−0.1439	0.0723	2.98	0.9986	0.0047	0.0371	−0.0825	0.1345
2.49	0.9936	0.0180	0.0935	−0.1432	0.0762	2.99	0.9986	0.0046	0.0363	−0.0811	0.1337
2.50	0.9938	0.0175	0.0920	−0.1424	0.0800	3.00	0.9987	0.0044	0.0355	−0.0798	0.1330
2.51	0.9940	0.0171	0.0906	−0.1416	0.0836	3.01	0.9987	0.0043	0.0347	−0.0785	0.1321
2.52	0.9941	0.0167	0.0892	−0.1408	0.0871	3.02	0.9987	0.0042	0.0339	−0.0771	0.1313
2.53	0.9943	0.0163	0.0878	−0.1399	0.0905	3.03	0.9988	0.0040	0.0331	−0.0758	0.1304
2.54	0.9945	0.0158	0.0864	−0.1389	0.0937	3.04	0.9988	0.0039	0.0324	−0.0745	0.1294
2.55	0.9946	0.0154	0.0850	−0.1380	0.0968	3.05	0.9989	0.0038	0.0316	−0.0732	0.1285
2.56	0.9948	0.0151	0.0836	−0.1370	0.0998	3.06	0.9989	0.0037	0.0309	−0.0720	0.1275
2.57	0.9949	0.0147	0.0823	−0.1360	0.1027	3.07	0.9989	0.0036	0.0302	−0.0707	0.1264
2.58	0.9951	0.0143	0.0809	−0.1350	0.1054	3.08	0.9990	0.0035	0.0295	−0.0694	0.1254
2.59	0.9952	0.0319	0.0796	−0.1339	0.1080	3.09	0.9990	0.0034	0.0288	−0.0682	0.1243
2.60	0.9953	0.0136	0.0782	−0.1328	0.1105	3.10	0.9990	0.0033	0.0281	−0.0669	0.1231
2.60	0.9953	0.0136	0.0782	−0.1328	0.1105	3.11	0.9991	0.0032	0.0275	−0.0657	0.1220
2.62	0.9956	0.0129	0.0756	−0.1305	0.1152	3.12	0.9991	0.0031	0.0268	−0.0645	0.1208
2.63	0.9957	0.0126	0.0743	−0.1294	0.1173	3.13	0.9991	0.0030	0.0262	−0.0633	0.1196
2.64	0.9959	0.0122	0.0730	−0.1282	0.1194	3.14	0.9992	0.0029	0.0256	−0.0621	0.1184
2.65	0.9960	0.0119	0.0717	−0.1270	0.1213	3.15	0.9992	0.0028	0.0249	−0.0609	0.1171
2.66	0.9961	0.0116	0.0705	−0.1258	0.1231	3.16	0.9992	0.0027	0.0243	−0.0598	0.1159
2.67	0.9962	0.0113	0.0692	−0.1245	0.1248	3.17	0.9992	0.0026	0.0237	−0.0586	0.1146
2.68	0.9963	0.0110	0.0680	−0.1233	0.1264	3.18	0.9993	0.0025	0.0232	−0.0575	0.1133
2.69	0.9964	0.0107	0.0668	−0.1220	0.1279	3.19	0.9993	0.0025	0.0226	−0.0564	0.1120
2.70	0.9965	0.0104	0.0656	−0.1207	0.1293	3.20	0.9993	0.0024	0.0220	−0.0552	0.1107
2.71	0.9966	0.0101	0.0644	−0.1194	0.1306	3.21	0.9993	0.0023	0.0215	−0.0541	0.1093
2.72	0.9967	0.0099	0.0632	−0.1181	0.1317	3.22	0.9994	0.0022	0.0210	−0.0531	0.1080
2.73	0.9968	0.0096	0.0620	−0.1168	0.1328	3.23	0.9994	0.0022	0.0204	−0.0520	0.1066
2.74	0.9969	0.0093	0.0608	−0.1154	0.1338	3.24	0.9994	0.0021	0.0199	−0.0509	0.1053
2.75	0.9970	0.0091	0.0597	−0.1141	0.1347	3.25	0.9994	0.0020	0.0194	−0.0499	0.1039
2.76	0.9971	0.0088	0.0585	−0.1127	0.1356	3.26	0.9994	0.0020	0.0189	−0.0488	0.1025
2.77	0.9972	0.0086	0.0574	−0.1114	0.1363	3.27	0.9995	0.0019	0.0184	−0.0478	0.1011
2.78	0.9973	0.0084	0.0563	−0.1100	0.1369	3.28	0.9995	0.0018	0.0180	−0.0468	0.0997
2.79	0.9974	0.0081	0.0552	−0.1087	0.1375	3.29	0.9995	0.0018	0.0175	−0.0458	0.0983

Table 24 (*Continued*)

x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$	x	$\frac{1}{2}(1+\alpha)$	$\Phi(x)$	$\Phi^{(2)}(x)$	$\Phi^{(3)}(x)$	$\Phi^{(4)}(x)$
3.30	0.9995	0.0017	0.0170	−0.0449	0.0969	3.75	0.9999	0.0004	0.0046	−0.0146	0.0410
3.31	0.9995	0.0017	0.0106	−0.0439	0.0955	3.76	0.9999	0.0003	0.0045	−0.0142	0.0401
3.32	0.9996	0.0016	0.0102	−0.0429	0.0941	3.77	0.9999	0.0003	0.0043	−0.0138	0.0392
3.33	0.9996	0.0016	0.0157	−0.0420	0.0927	3.78	0.9999	0.0003	0.0042	−0.0134	0.0382
3.34	0.9996	0.0015	0.0153	−0.0411	0.0913	3.79	0.9999	0.0003	0.0041	−0.0131	0.0373
3.35	0.9996	0.0015	0.0149	−0.0402	0.0899	3.80	0.9999	0.0003	0.0039	−0.0127	0.0365
3.36	0.9996	0.0014	0.0145	−0.0393	0.0885	3.81	0.9999	0.0003	0.0038	−0.0123	0.0356
3.37	0.9996	0.0014	0.0141	−0.0384	0.0871	3.82	0.9999	0.0003	0.0037	−0.0120	0.0347
3.38	0.9996	0.0013	0.0138	−0.0376	0.0857	3.83	0.9999	0.0003	0.0036	−0.0116	0.0339
3.39	0.9997	0.0013	0.0134	−0.0367	0.0843	3.84	0.9999	0.0003	0.0034	−0.0113	0.0331
3.40	0.9997	0.0012	0.0130	−0.0359	0.0829	3.85	0.9999	0.0002	0.0033	−0.0110	0.0323
3.41	0.9997	0.0012	0.0127	−0.0350	0.0815	3.86	0.9999	0.0002	0.0032	−0.0107	0.0315
3.42	0.9997	0.0012	0.0123	−0.0342	0.0801	3.87	1.0000	0.0002	0.0031	−0.0104	0.0307
3.43	0.9997	0.0011	0.0120	−0.0334	0.0788	3.88	1.0000	0.0002	0.0030	−0.0100	0.0299
3.44	0.9997	0.0011	0.0116	−0.0327	0.0774	3.89	1.0000	0.0002	0.0029	−0.0098	0.0292
3.45	0.9997	0.0010	0.0113	−0.0319	0.0761	3.90	1.0000	0.0002	0.0028	−0.0095	0.0284
3.46	0.9997	0.0010	0.0110	−0.0311	0.0747	3.91	1.0000	0.0002	0.0027	−0.0092	0.0277
3.47	0.9997	0.0010	0.0107	−0.0304	0.0734	3.92	1.0000	0.0002	0.0026	−0.0089	0.0270
3.48	0.9998	0.0009	0.0104	−0.0297	0.0721	3.93	1.0000	0.0002	0.0026	−0.0086	0.0263
3.49	0.9998	0.0009	0.0101	−0.0290	0.0707	3.94	1.0000	0.0002	0.0025	−0.0084	0.0256
3.50	0.9998	0.0009	0.0098	−0.0283	0.0694	3.95	1.0000	0.0002	0.0024	−0.0081	0.0250
3.51	0.9998	0.0008	0.0095	−0.0276	0.0681	3.96	1.0000	0.0002	0.0023	−0.0079	0.0243
3.52	0.9998	0.0008	0.0093	−0.0269	0.0669	3.97	1.0000	0.0002	0.0022	−0.0076	0.0237
3.53	0.9998	0.0008	0.0090	−0.0262	0.0656	3.98	1.0000	0.0001	0.0022	−0.0074	0.0230
3.54	0.9998	0.0008	0.0087	−0.0256	0.0643	3.99	1.0000	0.0001	0.0021	−0.0072	0.0224
3.55	0.9998	0.0007	0.0085	−0.0249	0.0631	4.00	1.0000	0.0001	0.0020	−0.0070	0.0218
3.56	0.9998	0.0007	0.0082	−0.0243	0.0618	4.05	1.0000	0.0001	0.0017	−0.0059	0.0190
3.57	0.9998	0.0007	0.0080	−0.0237	0.0606	4.10	1.0000	0.0001	0.0014	−0.0051	0.0165
3.58	0.9998	0.0007	0.0078	−0.0231	0.0594	4.15	1.0000	0.0001	0.0012	−0.0043	0.0143
3.59	0.9998	0.0006	0.0075	−0.0225	0.0582	4.20	1.0000	0.0001	0.0010	−0.0036	0.0123
3.60	0.9998	0.0006	0.0073	−0.0219	0.0570	4.25	1.0000	0.0001	0.0008	−0.0031	0.0105
3.61	0.9999	0.0006	0.0071	−0.0214	0.0559	4.30	1.0000	0.0000	0.0007	−0.0026	0.0090
3.62	0.9999	0.0006	0.0069	−0.0208	0.0547	4.35	1.0000	0.0000	0.0006	−0.0022	0.0077
3.63	0.9999	0.0006	0.0067	−0.0203	0.0536	4.40	1.0000	0.0000	0.0005	−0.0018	0.0065
3.64	0.9999	0.0005	0.0065	−0.0198	0.0524	4.45	1.0000	0.0000	0.0004	−0.0015	0.0055
3.65	0.9999	0.0005	0.0063	−0.0192	0.0513	4.50	1.0000	0.0000	0.0003	−0.0012	0.0047
3.66	0.9999	0.0005	0.0061	−0.0187	0.0502	4.55	1.0000	0.0000	0.0003	−0.0010	0.0039
3.67	0.9999	0.0005	0.0059	−0.0182	0.0492	4.60	1.0000	0.0000	0.0002	−0.0009	0.0033
3.68	0.9999	0.0005	0.0057	−0.0177	0.0481	4.65	1.0000	0.0000	0.0002	−0.0007	0.0027
3.69	0.9999	0.0004	0.0056	−0.0173	0.0470	4.70	1.0000	0.0000	0.0001	−0.0006	0.0023
3.70	0.9999	0.0004	0.0054	−0.0168	0.0460	4.75	1.0000	0.0000	0.0001	−0.0005	0.0019
3.71	0.9999	0.0004	0.0052	−0.0164	0.0450	4.80	1.0000	0.0000	0.0001	−0.0004	0.0016
3.72	0.9999	0.0004	0.0051	−0.0159	0.0440	4.85	1.0000	0.0000	0.0001	−0.0003	0.0013
3.73	0.9999	0.0004	0.0049	−0.0155	0.0430	4.90	1.0000	0.0000	0.0001	−0.0003	0.0011
3.74	0.9999	0.0004	0.0048	−0.0150	0.0420	4.95	1.0000	0.0000	0.0000	−0.0002	0.0009

The sum of those terms of

$$(p+q)^n \equiv \sum_{t=0}^{n} \binom{n}{t} p^{n-t} q^t \qquad p+q=1$$

in which t ranges from a to b inclusive, a and b being integers ($a \leqq t \leqq b$), is (if n is large enough) approximately

$$\int_{x_1}^{x_2} \phi(x)\ dx + \left[\frac{q-p}{6\sigma}\phi^{(2)}(x) + \frac{1}{24}\left(\frac{1}{\sigma^2}-\frac{6}{n}\right)\phi^{(3)}(x)\right]_{x_1}^{x_2}$$

where $x_1 = (a - \frac{1}{2} - qn)/\sigma$, $x_2 = (b + \frac{1}{2} - qn)/\sigma$.

The sum of the first $t+1$ terms of

$$(p+q)^n \equiv \sum_{t=0}^{n} \binom{n}{t} p^{n-t} q^t \qquad p+q=1$$

is approximately

$$\int_{x}^{\infty} \phi(x)\ dx + \frac{q-p}{6\sigma}\phi^{(2)}(x) - \frac{1}{24}\left(\frac{1}{\sigma^2}-\frac{6}{n}\right)\phi^{(3)}(x)$$

where $x = (s - \frac{1}{2} - np)/\sigma$, $s = n - t$. The sum of the last $s+1$ terms is approximately

$$\int_{x}^{\infty} \phi(x)\, dx - \frac{q-p}{6\sigma}\phi^{(2)}(x) - \frac{1}{24}\left(\frac{1}{\sigma^2}-\frac{6}{n}\right)\phi^{(3)}(x)$$

where $x = (t - \frac{1}{2} - nq)/\sigma$.

Table 25 Factors for Computing Probable Errors

n	$\frac{1}{\sqrt{n}}$	$\frac{1}{\sqrt{n(n-1)}}$	$\frac{0.6745}{\sqrt{n-1}}$	$\frac{0.6745}{\sqrt{n(n-1)}}$	$\frac{0.8453}{n\sqrt{n-1}}$	$\frac{0.8453}{\sqrt{n(n-1)}}$
2	0.707 107	0.707 107	0.6745	0.4769	0.4227	0.5978
3	0.577 350	0.408 248	0.4769	0.2754	0.1993	0.3451
4	0.500 000	0.288 675	0.3894	0.1947	0.1220	0.2440
5	0.447 214	0.223 607	0.3372	0.1508	0.0845	0.1890
6	0.408 248	0.182 574	0.3016	0.1231	0.0630	0.1543
7	0.377 964	0.154 303	0.2754	0.1041	0.0493	0.1304
8	0.353 553	0.133 631	0.2549	0.0901	0.0399	0.1130
9	0.333 333	0.117 851	0.2385	0.0795	0.0332	0.0996
10	0.316 228	0.105 409	0.2248	0.0711	0.0282	0.0891
11	0.301 511	0.095 346	0.2133	0.0643	0.0243	0.0806
12	0.288 675	0.087 039	0.2034	0.0587	0.0212	0.0736
13	0.277 350	0.080 064	0.1947	0.0540	0.0188	0.0677
14	0.267 261	0.074 125	0.1871	0.0500	0.0167	0.0627
15	0.258 199	0.069 007	0.1803	0.0465	0.0151	0.0583
16	0.250 000	0.064 550	0.1742	0.0435	0.0136	0.0546
17	0.242 536	0.060 634	0.1686	0.0409	0.0124	0.0513
18	0.235 702	0.057 166	0.1636	0.0386	0.0114	0.0483
19	0.229 416	0.054 074	0.1590	0.0365	0.0105	0.0457
20	0.223 607	0.051 299	0.1547	0.0346	0.0097	0.0434
21	0.218 218	0.048 795	0.1508	0.0329	0.0090	0.0412
22	0.213 201	0.046 524	0.1472	0.0314	0.0084	0.0393
23	0.208 514	0.044 455	0.1438	0.0300	0.0078	0.0376
24	0.204 124	0.042 563	0.1406	0.0287	0.0073	0.0360
25	0.200 000	0.040 825	0.1377	0.0275	0.0069	0.0345
26	0.196 116	0.039 223	0.1349	0.0265	0.0065	0.0332
27	0.192 450	0.037 743	0.1323	0.0255	0.0061	0.0319
28	0.188 982	0.036 370	0.1298	0.0245	0.0058	0.0307
29	0.185 695	0.035 093	0.1275	0.0237	0.0055	0.0297
30	0.182 574	0.033 903	0.1252	0.0229	0.0052	0.0287
31	0.179 605	0.032 791	0.1231	0.0221	0.0050	0.0277
32	0.176 777	0.031 750	0.1211	0.0214	0.0047	0.0268
33	0.174 078	0.030 773	0.1192	0.0208	0.0045	0.0260
34	0.171 499	0.029 854	0.1174	0.0201	0.0043	0.0252

Table 25 (*Continued*)

n	$\frac{1}{\sqrt{n}}$	$\frac{1}{\sqrt{n(n-1)}}$	$\frac{0.6745}{\sqrt{n-1}}$	$\frac{0.6745}{\sqrt{n(n-1)}}$	$\frac{0.8453}{n\sqrt{n-1}}$	$\frac{0.8453}{\sqrt{n(n-1)}}$
35	0.169 031	0.028 989	0.1157	0.0196	0.0041	0.0245
36	0.166 667	0.028 172	0.1140	0.0190	0.0040	0.0238
37	0.164 399	0.027 400	0.1124	0.0185	0.0038	0.0232
38	0.162 221	0.026 669	0.1109	0.0180	0.0037	0.0225
39	0.160 128	0.025 976	0.1094	0.0175	0.0035	0.0220
40	0.158 114	0.025 318	0.1080	0.0171	0.0034	0.0214
41	0.156 174	0.024 693	0.1066	0.0167	0.0033	0.0209
42	0.154 303	0.024 098	0.1053	0.0163	0.0031	0.0204
43	0.152 499	0.023 531	0.1041	0.0159	0.0030	0.0199
44	0.150 756	0.022 990	0.1029	0.0155	0.0029	0.0194
45	0.149 071	0.022 473	0.1017	0.0152	0.0028	0.0190
46	0.147 442	0.021 979	0.1005	0.0148	0.0027	0.0186
47	0.145 865	0.021 507	0.0994	0.0145	0.0027	0.0182
48	0.144 338	0.021 054	0.0984	0.0142	0.0026	0.0178
49	0.142 857	0.020 620	0.0974	0.0139	0.0025	0.0174
50	0.141 421	0.020 203	0.0964	0.0136	0.0024	0.0171
51	0.140 028	0.019 803	0.0954	0.0134	0.0023	0.0167
52	0.138 675	0.019 418	0.0945	0.0131	0.0023	0.0164
53	0.137 361	0.019 048	0.0935	0.0129	0.0022	0.0161
54	0.136 083	0.018 692	0.0927	0.0126	0.0022	0.0158
55	0.134 840	0.018 349	0.0918	0.0124	0.0021	0.0155
56	0.133 631	0.018 019	0.0910	0.0122	0.0020	0.0152
57	0.132 453	0.017 700	0.0901	0.0119	0.0020	0.0150
58	0.131 306	0.017 392	0.0893	0.0117	0.0019	0.0147
59	0.130 189	0.017 095	0.0886	0.0115	0.0019	0.0145
60	0.129 099	0.016 807	0.0878	0.0113	0.0018	0.0142
61	0.128 037	0.016 529	0.0871	0.0112	0.0018	0.0140
62	0.127 000	0.016 261	0.0864	0.0110	0.0018	0.0138
63	0.125 988	0.016 001	0.0857	0.0108	0.0017	0.0135
64	0.125 000	0.015 749	0.0850	0.0106	0.0017	0.0133
65	0.124 035	0.015 504	0.0843	0.0105	0.0016	0.0131
66	0.123 091	0.015 268	0.0837	0.0103	0.0016	0.0129
67	0.122 169	0.015 038	0.0830	0.0101	0.0016	0.0127
68	0.121 268	0.014 815	0.0824	0.0100	0.0015	0.0125
69	0.120 386	0.014 599	0.0818	0.0099	0.0015	0.0123
70	0.119 523	0.014 389	0.0812	0.0097	0.0015	0.0122
71	0.118 678	0.014 185	0.0806	0.0096	0.0014	0.0120
72	0.117 851	0.013 986	0.0801	0.0094	0.0014	0.0118
73	0.117 041	0.013 793	0.0795	0.0093	0.0014	0.0117
74	0.116 248	0.013 606	0.0789	0.0092	0.0013	0.0115
75	0.115 470	0.013 423	0.0784	0.0091	0.0013	0.0113
76	0.114 708	0.013 245	0.0779	0.0089	0.0013	0.0112
77	0.113 961	0.013 072	0.0773	0.0088	0.0013	0.0111
78	0.113 228	0.012 904	0.0769	0.0087	0.0012	0.0109
79	0.112 509	0.012 739	0.0764	0.0086	0.0012	0.0108
80	0.111 803	0.012 579	0.0759	0.0085	0.0012	0.0106
81	0.111 111	0.012 423	0.0754	0.0084	0.0012	0.0105
82	0.110 432	0.012 270	0.0749	0.0083	0.0012	0.0104
83	0.109 764	0.012 121	0.0745	0.0082	0.0011	0.0103
84	0.109 109	0.011 976	0.0740	0.0081	0.0011	0.0101

(*Continues*)

Table 25 (*Continued*)

n	$\frac{1}{\sqrt{n}}$	$\frac{1}{\sqrt{n(n-1)}}$	$\frac{0.6745}{\sqrt{n-1}}$	$\frac{0.6745}{\sqrt{n(n-1)}}$	$\frac{0.8453}{n\sqrt{n-1}}$	$\frac{0.8453}{\sqrt{n(n-1)}}$
85	0.108 465	0.011 835	0.0736	0.0080	0.0011	0.0100
86	0.107 833	0.011 696	0.0732	0.0079	0.0011	0.0099
87	0.107 211	0.011 561	0.0727	0.0078	0.0011	0.0098
88	0.106 600	0.011 429	0.0723	0.0077	0.0010	0.0097
89	0.106 000	0.011 300	0.0719	0.0076	0.0010	0.0096
90	0.105 409	0.011 173	0.0715	0.0075	0.0010	0.0094
91	0.104 828	0.011 050	0.0711	0.0075	0.0010	0.0093
92	0.104 257	0.010 929	0.0707	0.0074	0.0010	0.0092
93	0.103 695	0.010 811	0.0703	0.0073	0.0010	0.0091
94	0.103 142	0.010 695	0.0699	0.0072	0.0009	0.0090
95	0.102 598	0.010 582	0.0696	0.0071	0.0009	0.0089
96	0.102 062	0.010 471	0.0692	0.0071	0.0009	0.0089
97	0.101 535	0.010 363	0.0688	0.0070	0.0009	0.0088
98	0.101 015	0.010 257	0.0685	0.0069	0.0009	0.0087
99	0.100 504	0.010 152	0.0681	0.0069	0.0009	0.0086
100	0.100 000	0.010 050	0.0678	0.0068	0.0008	0.0085

Table 26 Statistics and Probability Formulas

$p(x) = dP(x)/dx$	Differential probability (density) function of random variable x; univariate frequency function
$P(x) = \int_{-\infty}^{x} p(x')\,dx'$	Cumulative probability function of random variable x; univariate distribution function
$P(A < x < B)$	Cumulative probability that x is between A and B
$P(E \cap F)$	Probability of simultaneous (joint) occurrence of E and F
$P(E \cup F)$	Probability of occurrence of E or F or both
$P(E\|F) = P(E \cap F)/P(F)$	Conditional probability; probability of occurrence of E provided F has occurred
$E[f(x)] = \int_{-\infty}^{\infty} f(x)p(x)\,dx$	Expected value of function of a random variable x
$E(x) = \overline{x} = \int_{-\infty}^{\infty} xp(x)\,dx$	Expected (mean) value of random variable x
$\alpha_r = E(x^r)$	rth moment of random variable x; rth moment about the origin
$\mu_r = E(x - \overline{x})^r$	rth moment of random variable x from mean value; r th central moment
$\text{Var } x = E[(x - \overline{x})^2] = \overline{(x - \overline{x})^2}$ $= \overline{x^2} - \overline{x}^2$	Variance value of random variable x
$\sigma = (\text{Var } x)^{1/2}$	Standard deviation of random variable x
$M_x(s) = E(e^{sx})$	Moment generating function associated with random variable x
$\psi_x(q) = E(e^{jqx})$	Characteristic function associated with random variable x
$\psi_g(q) = E[e^{jqg(x)}]$	Characteristic function of $g(x)$ with random variable x
$p(x, y) = d^2P(x, y)/dx\,dy$	Differential probability (density) function of random variables x and y; bivariate frequency function
$P(x, y) = \int_{-\infty}^{x} \int_{-\infty}^{y} p(x', y')\,dx'\,dy'$	Cumulative probability function of random variables x and y; bivariate distribution function
$P(A < x < B, C < y < D)$	Cumulative probability that x is between A and B and that also y is between C and D; cumulative joint probability
$\text{Cov }(x, y) = E[(x - \overline{x})(y - \overline{y})]$ $= \overline{(x - \overline{x})(y - \overline{y})}$	Covariance value of random variables x and y
$\rho(x, y) = \text{Cov }(x, y)/\sigma_x\sigma_y$	Correlation coefficient of random variables x and y

Source: Giacoletto, *Electronic Designers' Handbook*, Copyright © 1977 by McGraw-Hill, pp. 1–8.

The *probable error* of a single observation in a series of n measures, $t_1, t_2, \ldots, t_n$, the arithmetic mean of which is m, is

$$e = \frac{0.6745}{\sqrt{n-1}} \sqrt{(m-t_1)^2 + (m-t_2)^2 + \cdots + (m-t_n)^2}$$

the probable error of the mean is

$$E = \frac{0.6745}{\sqrt{n(n-1)}} \times \sqrt{(m-t_1)^2 + (m-t_2)^2 + \cdots + (m-t_n)^2}$$

Approximate values of e and E are

$$e = 0.8453 \frac{\sum_{i=1}^{n} d_i}{\sqrt{n(n-1)}} \qquad E = 0.8453 \frac{\sum_{i=1}^{n} d_i}{n\sqrt{n-1}}$$

where $\sum_{i=1}^{n} d_i$ is the sum of the deviations $d_i = |t_i - m|$.

4 UNITS AND STANDARDS

4.1 Physical Quantities and Their Relations

Mathematics is concerned with relations between numerical quantities, either constant or varying in a specified manner over a specified range of values. The numerical values are unique, absolute, and the same all over the world, being the expression of a fundamental perception of the mind. Any *mathematical equation* defines the values of one numerical quantity, known as the dependent, in terms of constants and one or more other numerical quantities, known as the independent variables, as, for example,

$$z = r^2 + 3x + 4 \qquad y = c \cdot \int_0^x \frac{x^2}{\cos x}\, dx \tag{1}$$

where z and y are dependent variables, r and x independent variables, and c a constant.

Physics, comprising the knowledge of inanimate nature and its laws, is concerned fundamentally with the measuring of the various quantities founded or created by definition, as, for example, *length, mass*, and *electric charge*. In order to specify a *physical quantity* it is not sufficient to state merely a number. The value of a physical quantity can be determined only by comparison of the sample with a known amount of the same quantity by the process of *measuring*. The reference amount is called a unit, and the result of any measurement must be a statement of "how many times the sample was found to contain the reference amount." Thus a physical quantity Q naturally appears to be the product of a numerical value N and a unit U,

$$Q = N \cdot U \tag{2}$$

as, for example: The length of a particular rod is 3.5 ft, or the rod is $3\frac{1}{2}$ times the length of 1 ft. Obviously, the reproduction of a unit must be possible at any time in order to facilitate correct measurements. This is being done by means of the "standards," which are simply a set of fundamental unit quantities kept under normalized conditions in order to preserve their values as accurately as facilities permit.

Any physical relation must be the result of a more or less obvious measurement, so that equations in physics are not merely numerical relations but express dependencies between physical quantities. Mathematics does not know "standards"; physics cannot be without "standards." The fact that physics often uses the methods of mathematics must not lead to the identification of the two sciences; it is merely an overlapping in the border regions.

Relations between Units. A unit is a particular amount of the physical quantity to be measured defined in terms of a standard. The choice of a unit depends on convenience, facility of reproduction, and easy subdivision so as to obtain smaller units if desired. The value of a physical quantity Q must be independent of the units used, so that for two different units of the same type

$$Q = N_1 \cdot U_1 = N_2 \cdot U_2 \tag{3}$$

The size of the unit and the numerical value of the quantity are inversely related: the larger the unit the smaller the number of units.

A unit relation is an equation between two different units of the same type,

$$U_1 = N_{12} \cdot U_2 \tag{4}$$

and serves to convert from one unit U_1 to a different one U_2. The conversion is achieved by replacing U_1, taken as a factor, by its equivalent according to Eq. (4) so that

$$Q = N_1 \cdot U_1 = N_1 \cdot (N_{12} \cdot U_2) = (N_1 \cdot N_{12}) \cdot U_2 \tag{5}$$

As an example, express the length 3.5 ft in centimeters. The unit relation is 1 ft = 30.5 cm, and therefore $l = 3.5$ ft $= 3.5 \times (30.5$ cm$) = 106.75$ cm. No error is possible if this rule is followed properly.

Physical Equations. Relations between physical quantities are usually given in the form of equations. It is always possible, by the proper use of unit relations (see previous paragraph), to express each side in the same units. Since units are to be considered as factors, they may be canceled and a numerical identity must result. This fact always can be used to check the proper numerical relations and the consistency of the units used.

There are two fundamental types of physical equations:

1. The **mathematical definition** of a physical quantity determines a new quantity uniquely in terms of known quantities. An example is Newton's definition of mass by $f = m \cdot a$, where f is the force and a the acceleration of a moving body. If f and a are measured, m can be computed as a physical quantity with numerical value $N(f)/N(a)$ and unit $U(f)/U(a) = U(m)$. A definition should be in agreement with all the other known relations in a particular field of science; it can only be of restricted value if it contradicts other relations (see later the "absolute" electric systems).

2. The **statement of proportionality** defines one physical quantity as linearly depending on a combination of other, known quantities. It is always the result of an experimental investigation. An example is Newton's law of the gravitational force $f = k(m_1 m_2/r^2)$, where m_1 and m_2 are the two masses, r their center distance, and k the proportionality factor. In the case of a proportionality it is permissible to choose arbitrary units for all measurable physical quantities involved and to use the equation as a definition of the proportionality constant that, in general, will be a physical constant with numerical value and unit. In the example the value of k would be

$$\frac{N(f) \cdot N(r^2)}{N(m_1) \cdot N(m_2)} \times \frac{U(f) \cdot U(r^2)}{U(m_1) \cdot U(m_2)} = N(k) \cdot U(k)$$

Most of the fundamental laws of physics are statements of proportionalities, leading to universal physical constants, as, for instance, the gravitational constant k, the Planck constant h, the gas constant R, the absolute permeability of free space μ_v, and the absolute dielectric constant of free space ε_u. It may be observed that each branch of physics is represented by at least one fundamental proportionality constant.

Derived physical quantities are, in general, the result of mathematical definitions. The units of derived quantities are expressed from the combinations of the units used in the definition. All proportionality constants are ordinarily considered as derived physical quantities.

Fundamental Physical Quantities. The physical quantities, arbitrarily chosen to define new quantities or derived quantities, are called fundamental physical quantities. Their number may vary according to needs and convenience. There is no possibility to designate any physical quantity as absolutely fundamental, or a priori fundamental. Quantities that appear to be fundamental in one special field may be derived quantities in some other field.

4.2 Dimensions and Dimension Systems

Definition of Dimension. To choose a unit for a physical quantity one has an infinity of possibilities. The numerous units of length that were in use about 100 years ago present a good practical illustration. Yet all these units have in common the quality of being a distinct length and not, for example, a volume. It is convenient to state this fact by representing with the notation $[L]$ any unit of length whatsoever. The measurement of a physical quantity Q, therefore, leads to the statement

$$Q = N \cdot [Q] \tag{6}$$

where N is a numeric denoting the number of general units $[Q]$ that constitute the total quantity Q. According to Fourier, who first introduced this concept into the literature, $[Q]$ is called the "dimension" of the quantity Q. Be it clearly understood that dimension is simply the expression of a general unit and therefore a characteristic peculiarity of physical quantities not occurring in mathematics. Each new physical quantity gives rise to a new "dimension", as, for instance, time $[T]$, force $[F]$, mass $[M]$, and so on. There are as many dimensions, or general units, as there are kinds of physical quantities.

Derived Dimensions. Many physical quantities have been introduced by mathematical definition. Velocity, for example, is defined as $v = ds/dt$, where s is the length of the path measured from a definite origin and t is the time. A possible expression for the dimension of velocity would be $[V]$. It is customary and convenient, however, to make use of the mathematical definition that is but the rule for the measurement of velocity and to express the dimension in terms of the more familiar dimensions of length and time as a derived dimension $[V] = [L]/[T] = [L][T]^{-1}$. [Read: velocity is of $+1$ dimension in length and -1 dimension in time.] The use of mathematical definitions, leading to derived dimensions of a composite nature, reduces the number of symbols. Thus the measurement of volume, if scientifically conducted, gives $[\mathrm{Vol}] = [L]^3$, or in words, "volume is of $+3$ dimensions in length $[L]$."

Proportionality constants of physics have, in general, *derived dimensions*, as they are defined by the corresponding physical equations.

Fundamental Dimensions. The more familiar dimensions used to express derived dimensions are referred to as fundamental dimensions. It is advantageous to use as few of these fundamental dimensions as possible, not because the physical relations become simpler or clearer, but merely as a matter of economy in symbols. In fact, any dimension can be chosen to be a fundamental dimension in a particular field and a derived dimension in some other field of physics. No fundamental dimension can be made a starting point of natural philosophy.

Dimensional Equations. Since a physical equation constitutes in fact two equations, one for the units and one for the numerics, one can disregard the numerical factors entirely and write the general units or dimensions only, arriving thus at a dimensional equation. For instance, the law of gravitation would read $[F] = [k][M]^2[L]^{-2}$ using $[F]$, $[k]$, $[M]$, and $[L]$ as dimensions for force, gravitation constant, mass, and length, respectively. From this dimensional equation a derived dimension can be obtained for any quantity involved. Conversely, dimensional equations are used to check the correctness of physical relations if all dimensions can be made to cancel. Finally, the validity of dimensional equations leads to the method of dimensional analysis.

A *set of fundamental dimensions* is any group of fundamental dimensions convenient and useful to express all the physical quantities of a particular field in terms of derived dimensions. The number of fundamental dimensions to make a set may vary according to the field of application. Whether or not a set of fundamental dimensions can be used beyond the field for which it was originally intended will depend upon its suitability as a dimension system. (See next paragraph.) In no case should it be used where it can lead to confusion.

A set of fundamental dimensions is *incomplete* when the number of fundamental dimensions composing it is less than the number required for a dimension system. Incomplete sets of fundamental dimensions should not be used outside the very restricted field for which they are defined; they necessarily would lead to confusing relations.

A *dimension system* is composed of the smallest number of fundamental dimensions that will form a consistent and complete set for a field of science. Since each relation between physical quantities can be split up into one relation of numerics and another one of dimensions (as general units), it is possible to combine all known relations of dimensions. In setting up these relations, all proportionality factors must be taken as physical quantities. If there are m independent relations known, $m + p$ dimensions may be involved, of which m dimensions can be expressed by any p "fundamental" dimensions chosen arbitrarily.

This set of p "fundamental" dimensions is then called a dimension system. From the theory of numbers, therefore, it is known that one generally has a choice of $\binom{m+p}{p}$ possible dimension systems. Thus, if $p = 3$, $m = 3$, then one has $\binom{6}{3} = 20$ different possibilities. A necessary condition, however, is that *each* independent relation involve at least $p + 1$ dimensions. If this is not the case, then the number of possible dimension systems is less, so that $\binom{m+p}{p}$ indicates the *upper* limit.

Any dimension system chosen in the described manner is consistent, as well as correct, and never leads to ambiguity with respect to the expression of physical quantities. Complete dimension systems in mechanics must have three, in thermodynamics four, and in electromagnetism four fundamental dimensions. It seems, according to present knowledge, that five fundamental dimensions suffice for the entire range of physics, namely, the three fundamental dimensions of mechanics, an additional one for thermodynamics, and another additional one for electromagnetism.

All the known dimension systems use length $[L]$ and time $[T]$ as primary fundamental dimensions, adding various fundamental dimensions from the available physical quantities of the fields of physics. The choice of $[L]$ and $[T]$ reduces at once the maximum number of possible dimension systems to $\binom{m+p-2}{p-2}$.

Why Dimension Systems? Since the proper choice of units is the ultimate goal of any critical analysis of physical quantities, the question may be asked: Why is it necessary to discuss dimension of systems? The answer is that each physical quantity may be measured by an infinite variety of units but has only one dimension within a given dimension system. The process of deciding upon the fundamental dimensions before fixing the units within the scope of the fundamental dimensions is, therefore, essentially a matter of economy and logic.

4.3 Dimension and Unit Systems

In the past different dimension systems were introduced for various fields of technology (mechanics, heat, electromagnetism) and based on different choices of fundamental dimensions, for example, for mechanics, length and time plus mass or force or energy or gravitational constant gave potentially four different dimension system classes. In turn, for a given dimensional system, a unit system could be developed, choosing for each fundamental dimension a unit desirably related to a fundamental standard or standards. In seeking to define units with appropriate size values, relationships, and so on, many different unit systems, for example, centimeter–gram–second (cgs), meter–kilogram–second (mks), "absolute," "technical," and so on, have been introduced over the years. (See O. W. Eshbach and M. Souders, *Handbook of Engineering Fundamentals*, 3rd ed., Wiley, New York, 1975, for a detailed exposition of the subject.)

In recent years a major step toward simplification and standardization has been taken by the increasing adoption of the International System of Units (SI).

4.4 The International System of Units

The SI system, composed of six fundamental units, has been adopted by the Conference Générale (BIPM Sevres, Paris, 1954 and 1960) to cover the whole range of physics and one in which all international reports are to be expressed.

Quantity	Unit	Symbol
	Fundamental Units	
Length	Meter	m
Mass	Kilogram	kg
Time	Second	s
Intensity of electric current	Ampere	A
Thermodynamic temperature	Degree kelvin	K
Luminous intensity	Candela	cd
Amount of substance	Mole	mol
	Derived Units with Special Names	
Area	Square meter	m^2
Volume	Cubic meter	m^3
Frequency	Hertz	Hz
Density (mass density)	Kilogram per cubic meter	kg/m^3
Velocity	Meter per second	m/s
Angular velocity	Radian per second	rad/s
Acceleration	Meter per square second	m/s^2
Angular acceleration	Radian per square second	rad/s^2
Force	Newton	N, $kg.m/s^2$
Pressure, stress	Newton per square meter	N/m^2
Kinematic viscosity	Square meter per second	m^2/s
Dynamic viscosity	Newton-second per square meter	$N.s/m^2$
Work, energy, heat (quantity of heat)	Joule	J, $N \cdot m$
Power, radiant flux	Watt	W, J/s
Plane angle	Radian	rad
Solid angle	Steradian	sr
Electric charge	Coulomb	C, $A \cdot s$
Electric potential, potential difference, electromotive force	Volt	V, W/A
Electric field strength	Volt per meter	V/m
Resistance (to direct current)	Ohm	Ω, V/A
Electric conductance	Siemens	S, A/V
Capacitance	Farad	F, $A \cdot s/V$
Magnetic flux	Weber	Wb, $V \cdot s$
Inductance	Henry	H, $V \cdot s/A$
Magnetic flux density (magnetic induction)	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
Illumination	Lux	lx, lm/m^2
Activity (of a radionuclide)	Becquerel	Bq, l/S
Absorbed dose	Gray	Gy, J/kg
Dose equivalent	Sievert	Sv, J/kg
	Other Common Derived Units	
Absorbed dose rate	Gray per second	Gy/s
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
Concentration (of amount of substance)	Mole per cubic meter	mol/m^3
Current density	Ampere per square meter	A/m^2

Quantity	Unit	Symbol
	Other Common Derived Units (Continued)	
Density, mass	Kilogram per cubic meter	kg/m^3
Electric charge density	Coulomb per cubic meter	C/m^3
Electric field strength	Volt per meter	V/m
Electric flux density	Coulomb per square meter	C/m^2
Energy density	Joule per cubic meter	J/m^3
Entropy	Joule per kelvin	J/K
Exposure (X and gamma rays)	Coulomb per kilogram	C/kg
Heat capacity	Joule per kelvin	J/K
Heat flux density	Watt per square meter	W/m^2
Irradiance	Watt per square meter	W/m^2
Luminance	Candela per square meter	cd/m^2
Magnetic field strength	Ampere per meter	A/m
Molar energy	Joule per mole	J/mol
Molar entropy	Joule per mole kelvin	$J/(mol \cdot K)$
Molar heat capacity	Joule per mole kelvin	$J/(mol \cdot K)$
Moment of force	Newton meter	$N \cdot m$
Permeability (magnetic)	Henry per meter	H/m
Permittivity	Farad per meter	F/m
Power density	Watt per square meter	W/m^2
Radiance	Watt per square meter steradian	$W/(m^2 \cdot sr)$
Radiant intensity	Watt per steradian	W/sr
Specific heat capacity	Joule per kilogram kelvin	$J/(kg \cdot K)$
Specific energy	Joule per kilogram	J/kg
Specific entropy	Joule per kilogram kelvin	$J/(kg \cdot K)$
Specific volume	Cubic meter per kilogram	m^3/kg
Surface tension	Newton per meter	N/m
Thermal conductivity	Watt per meter kelvin	$W/(m \cdot K)$
Velocity	Meter per second	m/s
Viscosity, dynamic	Pascal second	$Pa \cdot s$
Viscosity, kinematic	Square meter per second	m^2/s
Volume	Cubic meter	m^3
Wave number	1 per meter	1/m

Definitions of Derived Units of the International System Having Special Names

Quantity	Unit and Definition
1. Absorbed dose	The *gray* is the absorbed dose when the energy per unit mass imparted to matter by ionizing radiation is one joule per kilogram. *Note*: The gray is also used for the ionizing radiation quantities: specific energy imparted, kerma, and absorbed dose index, which have the SI unit joule per kilogram.
2. Activity	The *becquerel* is the activity of a radionuclide decaying at the rate of one spontaneous nuclear transition per second.
3. Celsius temperature	The *degree Celsius* is equal to the kelvin and is used in place of the kelvin for expressing Celsius temperature (symbol t) defined by the equation $t = T - T_0$, where T is the thermodynamic temperature and $T_0 = 273.15$ K by definition.
4. Dose equivalent	The *sievert* is the dose equivalent when the absorbed dose of ionizing radiation multiplied by the dimensionless factors Q (quality factor) and N (product of any other multiplying factors) stipulated by the International Commission on Radiological Protection is one joule per kilogram.

(*Continues*)

Quantity	Unit and Definition
5. Electric capacitance	The *farad* is the capacitance of a capacitor between the plates of which there appears a difference of potential of one volt when it is charged by a quantity of electricity equal to one coulomb.
6. Electric conductance	The *siemens* is the electric conductance of a conductor in which a current of one ampere is produced by an electric potential difference of one volt.
7. Electric inductance	The *henry* is the inductance of a closed circuit in which an electromotive force of one volt is produced when the electric current in the circuit varies uniformly at a rate of one ampere per second.
8. Electric potential difference, electromotive force	The *volt* (unit of electric potential difference and electromotive force) is the difference of electric potential between two points of a conductor carrying a constant current of one ampere when the power dissipated between these points is equal to one watt.
9. Electric resistance	The *ohm* is the electric resistance between two points of a conductor when a constant difference of potential of one volt, applied between these two points, produces in this conductor a current of one ampere, this conductor not being the source of any electromotive force.
10. Energy	The *joule* is the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of the force.
11. Force	The *newton* is that force that, when applied to a body having a mass of one kilogram, gives it an acceleration of one meter per second squared.
12. Frequency	The *hertz* is the frequency of a periodic phenomenon of which the period is one second.
13. Illuminance	The *lux* is the illuminance produced by a luminous flux of one lumen uniformly distributed over a surface of one square meter.
14. Luminous flux	The *lumen* is the luminous flux emitted in a solid angle of one steradian by a point source having a uniform intensity of one candela.
15. Magnetic flux	The *weber* is the magnetic flux that, linking a circuit of one turn, produces in it an electromotive force of one volt as it is reduced to zero at a uniform rate in one second.
16. Magnetic flux density	The *tesla* is the magnetic flux density given by a magnetic flux of one weber per square meter.
17. Power	The *watt* is the power that gives rise to the production of energy at the rate of one joule per second.
18. Pressure or stress	The *pascal* is the pressure or stress of one newton per square meter.
19. Quantity of electricity	The *coulomb* is the quantity of electricity transported in one second by a current of one ampere.

Prefixes. The SI system has adopted the following standard set of prefixes:

Multiplication Factor	Prefix	Symbol
$1\ 000\ 000\ 000\ 000\ 000\ 000 = 10^{18}$	Exa	E
$1\ 000\ 000\ 000\ 000\ 000 = 10^{15}$	Peta	P
$1\ 000\ 000\ 000\ 000 = 10^{12}$	Tera	T
$1\ 000\ 000\ 000 = 10^{9}$	Giga	G
$1\ 000\ 000 = 10^{6}$	Mega	M
$1\ 000 = 10^{3}$	Kilo	k
$100 = 10^{2}$	Hecto[a]	h
$10 = 10^{1}$	Deka[a]	da
$0.1 = 10^{-1}$	Deci[a]	d
$0.01 = 10^{-2}$	Centi[a]	c
$0.001 = 10^{-3}$	Milli	m
$0.000\ 001 = 10^{-6}$	Micro	µ
$0.000\ 000\ 001 = 10^{-9}$	Nano	n
$0.000\ 000\ 000\ 001 = 10^{-12}$	Pico	p
$0.000\ 000\ 000\ 000\ 001 = 10^{-15}$	Femto	f
$0.000\ 000\ 000\ 000\ 000\ 001 = 10^{-18}$	Atto	a

Application of SI Prefixes

General. In general the SI prefixes should be used to indicate orders of magnitude, thus eliminating nonsignificant digits and leading zeros in decimal fractions and providing a convenient alternative to the powers-of-10 notation preferred in computation. For example,

12,300 mm becomes 12.3 m

12.3×10^3 m becomes 12.3 km

0.00123 μA becomes 1.23 nA

Selection. When expressing a quantity by a numerical value and a unit, a prefix should preferably be chosen so that the numerical value lies between 0.1 and 1000. To minimize variety, it is recommended that prefixes representing 1000 raised to an integral power be used. However, three factors may justify deviation:

1. In expressing area and volume, the prefixes hecto-, deka-, deci-, and centi- may be required, for example, square hectometer, cubic centimeter.
2. In tables of values of the same quantity or in a discussion of such values within a given context, it is generally preferable to use the same unit multiple throughout.
3. For certain quantities in particular applications, one particular multiple is customarily used. For example, the millimeter is used for linear dimensions in mechanical engineering drawings even when the values lie far outside the range 0.1–1000 mm; the centimeter is often used for body measurements and clothing sizes.

Prefixes in Compound Units.* It is recommended that only one prefix be used in forming a multiple of a compound unit. Normally the prefix should be attached to a unit in the numerator. One exception to this is when the kilogram occurs in the denominator. For example,

V/m, *not* mV/mm, and MJ/kg, *not* kJ/g

Compound Prefixes. Compound prefixes formed by the juxtaposition of two or more SI prefixes are not to be used. For example, use

1 nm, *not* 1 mμm

1 pF, *not* 1μμ F

If values are required outside the range covered by the prefixes, they should be expressed by using powers of 10 applied to the base unit.

*A compound unit is a derived unit that is expressed in terms of two or more units rather than by a single special name.

Powers of Units. An exponent attached to a symbol containing a prefix indicates that the multiple or submultiple of the unit (the unit with its prefix) is raised to the power expressed by the exponent. For example,

$$1 \text{ cm}^3 = (10^{-2} \text{ m})^3 = 10^{-6} \text{ m}^3$$

$$1 \text{ ns}^{-1} = (10^{-9} \text{ s})^{-1} = 10^9 \text{ s}^{-1}$$

$$1 \text{ mm}^2/\text{s} = (10^{-3} \text{ m})^2/\text{s} = 10^{-6} \text{ m}^2/\text{s}$$

Calculations. Errors in calculations can be minimized if the base and the coherent derived SI units are used and the resulting numerical values are expressed in powers-of-10 notation instead of using prefixes.

Other Units

Units from Different Systems. To assist in preserving the advantage of SI as a coherent system, it is advisable to minimize the use with it of units from other systems. Such use should be limited to units listed in this section.

A following section presents conversion factors to and from SI units.

4.5 Length, Mass, and Time

English Units and Standards

Units of Length. The *foot* (ft) is the *fundamental* unit of length in the foot–pound–second (fps) system. It equals, by definition, one-third of a *yard* (yd), which is the English legalized *standard* unit of length. The *U.S. yard* was defined by Act of Congress, July 28, 1866, as 3600/3937 the length of the *meter*. (See discussion of metric system for definitions of metric length.)

In Great Britain, the *Imperial yard* is measured by a bronze bar preserved in the Standards Office, Westminster. Its length, in terms of the *international prototype meter*, is 3600/3937.0113 m. For engineering purposes, the U.S. and British *yards* may be considered identical.

As subunits, the *inch* (in.) is defined as one-twelfth of one standard foot, and the *mil* as the one-thousandth part of one inch. The *nautical mile* (mi) is defined as one minute of arc on the earth's surface at the equator, whereas the U.S. mile (U.S. mi statute) is exactly 5280 ft and practically identical with the British mile.

Unit of Capacity (Dry). The *bushel* (bu) is the *standard* unit of *dry* capacity. The *Winchester bushel* (U.S. standard) has a volume of 2150.42 in.^{3}

In Great Britain, the *Imperial bushel* (bu) is defined as the volume of 80 lb of pure water at 62°F weighed against brass weights in air at the same temperature as the water and with the barometer at 30 in. Its volume is approximately 2219.36 in.^{3}

Unit of Capacity (Liquid). The *gallon* (gal) is the *standard* unit of *liquid* capacity. The *U.S. gallon* has a volume of 231 in.^{3}

In Great Britain, the *Imperial gallon* is defined as the volume of 10 lb of pure water at 62°F weighed against brass weights in air at the same temperature as the water and with the barometer at 30 in. Its volume is approximately 277.420 in.^{3} The Imperial gallon (liquid measure) equals exactly one-eighth of the Imperial bushel (dry measure). Subunits are the quart (qt), which is one-fourth of the standard gallon, and the pint (pt), which is $\frac{1}{2}$ qt.

Units of Mass. The *pound* (*avoirdupois*) (lb avdp) is the *fundamental* unit of mass in the fps system.* It is also the English legalized *standard* unit of mass. The *U.S. pound* (*avoirdupois*) was defined by Act of Congress, 1866, as 1/2.2046 kg, but since 1895 there has been used, for greater accuracy, a value that agrees with that given by law as far as the latter is given, namely, 453.5924277 g. This value is now used by the Bureau of Standards as an exact definition and is the basis of the customary U.S. weights (Circular 47, Bureau of Standards).

In Great Britain, the *Imperial pound (avoirdupois)* is the mass of a *platinum cylinder* preserved in the Standards Office, Westminster. Its legal equivalent is 453.59243 g. For engineering purposes, the U.S. and British pounds (avoirdupois) may be considered as identical.

Subunits of mass are the grain (gr), defined as $\frac{1}{7000}$ of the standard pound (avoirdupois) and the ounce (avoirdupois) (oz-avdp), which is $\frac{1}{16}$ of the standard pound (avoirdupois). The grain was used as a fundamental unit in the so-called foot–gram–second (fgs) system of units prior to 1873.

Weight versus Mass. Unfortunately, the word "weight" is used in two different senses, namely, (1) by the layman (as well as loosely by the scientist) to designate a given *mass* or quantity of matter and (2) by the scientist to designate the *pull* in standard gravitational force units that is exerted by the earth upon a piece of matter. The result of the commercial act of "weighing" a specific quantity is independent of the local gravitational pull of the earth, since both spring scales and balances are calibrated locally by comparison with standard masses.

Auxiliary Fundamental Units. Auxiliary Fundamental Units and their principal derived units are defined and discussed under the sections of this handbook pertaining to the topics to which they apply. In general, however, conversion factors are included in the tables of Section 5.

*The slug of mass, which is extensively used by engineers and physicists, is (in the English system) the mass to which an acceleration of one foot per second per second would be given by the application of a one-pound force. Under any gravity conditions, 1 slug of mass = 32.1739 lb of mass.

For an interesting and rather complete history see *British Weights and Measures*, London, 1910, by Sir C. M. Watson.

Metric (or SI) Units and Standards The development of the SI system and the operations of the international bodies (BIPM, CIPM, and CGPM) having cognizance over weights and measures are described in appendices to ASTM's *Standard for Metric Practice* (ASTM E380-82, American Society for for Testing and Materials, Philadelphia, 1982).

Units of Length. The *centimeter* (cm) is the *fundamental* unit of length in the cgs system. It equals, by definition, $\frac{1}{100}$ of a *meter* (m). The meter has been standardized by international agreement as 1,650,763.73 times the wavelength in vacuum of the unperturbed transition ($2p_{10}$–$5d_5$) of krypton 86. The *basic* meter for international comparisons is the *international prototype meter*, which is the distance, at zero degrees Centigrade, between two lines on a platinum–iridium bar located at the International Bureau of Weights and Measures at Sèvres, France. This meter is the nearest to a duplicate ever constructed of the *original* meter, which was constructed and deposited in the Archives of the French Republic in 1799. The meter is very nearly equal to one ten-millionth of the distance, measured at sea level, from the equator to either pole.

An interesting history of the development of the *international prototype meter* (as well as the *international prototype kilogram*—see discussion on unit of mass) is given by W. Parry, National Bureau of Standards, in *Merriman's Civil Engineers' Handbook*, as follows:

> The use of the meter as the basis of geodetic surveys had become so general throughout Europe that a conference was called in Paris, France, in 1870, for the purpose of establishing a central bureau where the standards of the different countries could be compared. As a result of this conference an International Bureau of Weights and Measures was established near Paris in 1875, by the concurrent action of the principal nations of the world. One of the first tasks undertaken by the Bureau was the construction of exact copies of the meter and kilogram deposited in the Archives. Thirty-one standard meters of iridio-platinum and forty kilograms of the same alloy were constructed and carefully compared with the standards of the Archives and with one another. This great work was completed in 1889, and the meter and kilogram which agreed most nearly with the original standards were called international prototypes, and were deposited at the International Bureau, where they are maintained today subject to the authority of the International Committee on Weights and Measures. The remaining meters and kilograms were distributed by lot to the different nations which contributed to the support of the Bureau. The United States secured two copies of the meter and two copies of the kilogram, which are in the custody of

the Bureau of Standards at Washington. One of the meters, known as No. 27, and one kilogram, No. 20, were selected as the United States standards, while the other meter and kilogram are used as secondary standards. It was the declared intention of the International Committee that the various national prototypes should be returned to the International Bureau at regular intervals for the purpose of recomparing them with the international standards and with one another. In this way all measurements based upon metric standards throughout the world are ultimately referred to the international meter and kilogram.

Unit of Capacity. The *liter* (L) is the *standard* unit of capacity. It is defined as the volume of one kilogram of pure water at the temperature of maximum density (4°C) under a pressure of 76 cm of mercury. For all practical purposes, the liter may be regarded as the equivalent of the cubic decimeter, although the former is actually slightly greater, in the amount of less than three parts in one hundred thousand.

Unit of Mass. The *gram* (g) is the *fundamental* unit of mass in the cgs system.* It equals, by definition, $\frac{1}{1000}$ of a *kilogram* (kg), which is the *standard* unit of mass. The *basic* kilogram for international comparisons is the *international prototype kilogram*, which is a cylinder of platinum–iridium located at the International Bureau of Weights and Measures at Sèvres, France. This mass is the nearest to a duplicate ever constructed of the *original* kilogram, which was constructed and deposited in the Archives of the French Republic in 1799. The latter was made as nearly as possible equal to the mass of a cube of pure water at 4°C, the sides of the cube being one-tenth the length of the original meter.

An interesting history of the development of the *international prototype kilogram* was given under the discussion on units of length.

Weight versus Mass. See discussion under this same subheading of the English units and standards.

Auxiliary Fundamental Units. Auxiliary fundamental units and their principal derived units are defined and discussed under the sections of this handbook pertaining to the topics to which they apply. In general, however, conversion factors are included in Tables 27–64.

Standard of Time

Unit of Time. The *second* has been standardized by international agreement as 1/31,556,925.9747 of the tropical year at 12 hr, ephemeris time, January 0 for the year 1900.0. (This definition has been retained for the time being as an astronomical time standard—the following atomic standard of time interval is 100 times more precise.) The second has been standardized by international agreement as the time taken for 9,192,631,770.0 vibrations of the unperturbed hyperfine transition 4,0–3,0 for the $^2S_{1/2}$ fundamental state of the cesium 133 atom. The ^{133}Cs standard has been adopted provisionally (see resolution 5 of the 12th General Conference of Weights and Measures, BIPM, Sèvres, Paris, Oct. 1964). A more accurate hydrogen maser standard may be available in the near future that is 100 times more accurate than the ^{133}Cs standard.

Measures of Time. A *solar day* is measured by the rotation of the earth about its axis with respect to the sun. In *astronomical computations* and in *nautical time* the day commences at noon, and in the former it is counted throughout the 24 hr. In *civil computations* the day commences at midnight and is divided into two parts of 12 hr each.

A *solar year* is the time in which the earth makes one revolution around the sun. Its average time, called the *mean solar year*, is 365 days, 5 hr, 48 min, and 45.9747 sec, or nearly $365\frac{1}{4}$ days.

4.6 Force, Energy, and Power

Dynamical and Gravitational Units. According to the use of two different dimension and unit systems, the dynamical (or physical, or "absolute") system and the gravitational (or technical) system, two different sets of units of force, energy, power, and derived quantities are defined in both the English and the metric systems. *One dynamical unit of force* produces an acceleration of unity on unit standard mass. The *gravitational unit of force* is defined as that force required to give a unit standard mass an acceleration equal to that produced by the gravitational pull of the earth. As the acceleration due to gravity, g, varies with location and altitude,† the gravitational unit of force is not constant, and, therefore, its relation to the dynamical unit of force will vary. By international agreement, the value $g_0 = 980.665$ cm/sec sec $= 32.1739$ ft/sec sec (British) has been chosen as the standard acceleration of gravity to make invariant the gravitational unit of force.

English Units

Units of Force. The dynamical or physical unit of force is the *poundal*, defined as the force required to

*The slug of mass, which is extensively used by engineers and physicists, is (in the metric system) the mass to which an acceleration of one meter per second per second would be given by the application of a one-kilogram force. Under any gravity conditions, 1 slug of mass = 9.80665 kg of mass.

†The variation of g with latitude ϕ and altitude H is given approximately by (ϕ in degrees, H in meters) $g = 978.039\ (1 + 0.005295 \sin^2 \phi) - 0.000307H$. See *International Critical Tables*, Vol. 1, p. 395.

give a mass of one pound an acceleration of one foot per second per second.

The *pound-force* (or weight of the pound mass) is the gravitational or technical unit of force. It is, by definition, the force required to give a mass of one pound an acceleration of 32.1739 ft/sec sec. If a force is measured by "weighing," the result in pounds weight must be multiplied by g/g_0, the ratio of local to standard acceleration of gravity, in order to obtain the absolute value in pound-force units. For engineering purposes this correction can usually be neglected.

Unit of Pressure. This is defined as the unit of force acting upon a unit area. The most commonly employed unit is the *pound* (force) *per square inch*.

Standard atmospheric pressure is defined to be the force exerted by a column of mercury 760 mm (29.92 in.) high at 0°. This corresponds to 0.101325 MPa or 14.695 psi. Reference or fixed points for pressure calibration exist and are analogous to the phase changes used for temperature standards. These pressure references are based on phase changes or resistance jumps in selected materials.

Units of Work or Energy. The foot-poundal is the physical unit of work or energy and is defined as the work done by a force of one poundal in moving a body through the distance of one foot in the direction of the force.

The *foot-pound* (*force*) is the technical unit of work or energy and is defined as the work required to raise a mass (or weight) of one pound through a vertical distance of one foot at standard acceleration of gravity g_0. If measurements are made in places where the local value of the acceleration of gravity g is different from g_0, a correction factor g/g_0 must be applied if the exact value of work or energy is desired.

The *British thermal unit* (Btu) is the quantity of heat required to raise the temperature of a one-pound mass of water either at 39°F (at its maximum density) or at 60°F and standard pressure through 1°F. The mean British thermal unit is defined as the $\frac{1}{180}$ part of the heat required to raise the temperature of a one-pound mass of water from 32 to 212°F at standard pressure. It is obvious that the reference temperature must be indicated with the unit used.

Units of Power. Power is the time rate at which work is done. Its physical unit is the *foot-poundal per second*, its technical units are the *foot-pound (force) per second*, or the *British thermal unit per second*. The *horsepower* (hp or Hp) is defined as 33,000 ft-lb (force) per minute or 550 ft-lb (force) per second.

Units of Torque. Torque is the effectiveness of a force to produce rotation. It is defined as the product of the force and the perpendicular distance from its line of action to the instantaneous center of rotation. Its physical unit is the poundal-foot, and its technical unit the pound (force)-foot. (Note the reversal of force and length units in the designation of the units of torque as compared with the units of energy or work.)

Metric Units

Units of Force. The dynamical, or physical, unit of force is the *dyne*, defined as the force required to give a mass of one gram an acceleration of one centimeter per second per second.

The *newton* is the SI unit of force. It is the force required to give a mass of one kilogram an acceleration of one meter per second per second.

The *kilogram force* (or weight of the kilogram mass) is the gravitational or technical unit of force. It is, by definition, the force required to give a mass of one kilogram an acceleration of 980.665 cm/sec sec. If a force is measured by "weighing," the result in kilograms weight must be multiplied by g/g_0, the ratio of local to standard acceleration of gravity, in order to obtain the absolute value in kilogram-force units. For engineering purposes this correction can usually be neglected.

In the electrotechnical system of units the systematic unit of force is defined as the *joule per meter*, based on the fundamental definition of the joule. (See discussion on metric units of energy.)

Unit of Pressure. This is defined as the unit of force acting upon a unit of area.

The *newton per square meter* is the SI unit of pressure and is called the *pascal*.

The *kilogram force per square meter* is the technical unit of pressure. With respect to correction for local gravity, see discussion on force versus weight.

Pressure is measured also by the height in centimeters of the column of water at 4°C, or of the column of mercury at 0°C, which it supports. (See conversion Table 41.)

The *normal atmosphere* (*at*), or the standard atmospheric pressure, is defined as the pressure exerted by a column of 76 cm of mercury at sea level and 0°C at standard acceleration of gravity g_0. It is equal to 1.01321 bars or 1.0332 kg/cm^2 force and is used extensively in the engineering literature. Some confusion exists since the unit of 1 kg/cm^2 is occasionally called 1 practical atmosphere.

Units of Work or Energy. The *joule* is the physical or so-called absolute unit of work or energy. It is defined as the work done by a force of one newton acting through the distance of one meter. A larger unit is the *theoretical* or "absolute" *joule* defined as 10^7 ergs; it is a systematic unit in the practical electrical unit systems that is based on the theoretical unit systems. (See discussion on electrical units.)

The *international joule* is defined as the energy expended during one second by an electric current of one international ampere flowing through a resistance of one international ohm. (See discussion on electrical units.) The latest value of the international joule is equal to 1.000165 theoretical joules.*

The *kilowatt-hour* is the practical unit of energy in electrical metering. It is defined as a theoretical or an international unit (see definition of joule already given) and is equal to 3.6 megajoules.

The *meter-kilogram force* (commonly referred to as the kilogram-meter) is the technical unit of work or energy. It is defined as the work required to raise the mass (or weight) of one kilogram through a vertical distance of one meter at standard acceleration of gravity g_0. If measurements are made in places where the local value of the acceleration of gravity g is different from g_0, a correction factor g/g_0 has to be applied, if the exact value of work or energy is desired. (See discussion on force versus weight.)

The *gram-calorie* or small calorie is the physical unit of heat energy. It is defined as the quantity of heat required to raise the temperature of one gram mass of water either from 14.5 to 15.5°C or from 19.5 to 20.5°C at standard pressure. The two values are designated as 15 and 20°C cal, respectively. The mean gram-calorie is defined as $\frac{1}{100}$ part of the quantity of heat required to raise the temperature of one gram mass of water from 0 to 100°C at standard pressure. The same definitions apply to kilogram-calorie, or large calorie, if the kilogram mass is used as reference standard mass.

The *Ostwald calorie* is the quantity of heat required to raise the temperature of one gram mass from 0 to 100°C. This unit is frequently used by electrochemists and is equal to 100 mean gram-calories.

The *international kilocalorie* or international steam-table calorie (IT cal) is defined as the $\frac{1}{860}$ part of the international kilowatt-hour. This new unit avoids any reference to the thermal properties of water and was recommended for international adoption at the first International Steam Table Conference (1929).† Its value is very nearly equal to the mean kilocalorie, 1 IT cal = 1.00037 kilogram-calories (mean).

Units of Power. Power is the time rate at which work is done. Its physical unit is the watt, defined as the power which gives rise to the production of energy at the rate of one joule per second.

The *international watt* is defined as the power expended by an electric current of one international ampere flowing through a resistance of one international ohm. (See discussion on electrical units.) The latest value of the international watt is equal to 1.000165 theoretical watts.‡

The *electrical horsepower* is defined as 746 absolute watts and is commonly used in the United States and in England in rating electrical machinery.

*[*Mechanical Engineering*, Feb., 1930, pp. 122, 139.

†*Mechanical Engineering*, Nov., 1935, p. 710.

‡*Announcement of Changes in Electrical and Photometric Units*, Circular of National Bureau of Standards C459, Washington, DC, 1947.

The *meter-kilogram force per second* (commonly referred to as the kilogram-meter per second) is the technical unit of power. The *metric horsepower* is defined as 75 kg-m/sec and is the most common mechanical unit of power.

Units of Torque. Torque is the effectiveness of a force to produce rotation. It is defined as the product of the force and the perpendicular distance from its line of action to the instantaneous center of rotation. Its physical unit is the dyne-centimeter, and its technical unit the kilogram force meter. (Note the reversal of force and length units in the designation of the units of torque as compared with the units of energy and work.)

4.7 Thermal Units and Standards

Temperature

Definition of Temperature. The *temperature* of a body may be defined as its thermal state considered from the standpoint of its ability to communicate heat to other bodies. When two bodies are placed in thermal communication, the one that loses heat to the other is said to be at the higher temperature.

Standard Temperatures. Certain thermal states or "temperatures" may be reproduced and recognized by the fact that definite physical phenomena occur at these temperatures. Such thermal states are called "fixed points," and they may, quite apart from any temperature scale, be specified by the physical phenomena characteristic of those temperatures. The two fundamental fixed points are the ice point and the steam point.

The *ice point* is defined as the temperature of melting ice, which is realized experimentally as the temperature at which pure finely divided ice is in equilibrium with pure, air-saturated water under standard atmospheric pressure. The effect of increased pressure is to lower the freezing point to the extent of 0.007°C per atmosphere.

The *steam point* is defined as the temperature of condensing water vapor at standard atmospheric pressure, and it is realized experimentally by the use of a hypsometer so constructed as to avoid superheat of the vapor around the thermometer or contamination with air or other impurities. If the desired conditions have been attained, the observed temperature should be independent of the rate of heat supply to the boiler, except as this may affect the pressure within the hypsometer, and of the length of time the hypsometer has been in operation.

Definition of Temperature Scale. The purpose of establishing a temperature scale is to assign a number to every thermal state or temperature and to provide a means for determining the temperature of any particular body.

A *temperature scale* may be defined by (1) selecting definite numbers for certain fixed points, (2) selecting some physical property of a definite substance that varies with temperature, and (3) selecting a mathematical law expressing temperatures on the scale in question in terms of the selected property of the thermometric substance. For example, on the Centigrade mercury-in-glass scale, the ice and steam points are numbered 0 and 100, respectively, the relative or "apparent" expansion of a volume of mercury enclosed in glass of a definite kind is the property used, and the mathematical relation used to express temperature on this scale is that equal increments of apparent volume of the mercury in this glass correspond to equal increments of temperature. If some other substance is substituted for mercury, or if glass of a different kind is used, another scale is obtained that agrees with it at 0 and 100 but not at other temperatures.

Although, in general, a temperature scale depends on the thermometric substance as well as on the expression for the temperature in terms of some property of this substance, Lord Kelvin has shown that, if the property selected is the availability of energy, the scale so defined is wholly independent of the substance and depends only on the mathematical relation chosen. Any scale so defined is known as a thermodynamic scale.

Kelvin Temperature Scale. The temperature scale finally chosen by Lord Kelvin is the one on which the temperature interval from the ice point to the steam point is 100° and the ratio of the values of any two temperatures is equal to the ratio of the heat taken in to the heat rejected by a reversible thermodynamic engine working with a source and refrigerator at the higher and lower temperatures, respectively. On this scale, which is also known as the absolute thermodynamic scale, the lowest attainable temperature is 0 and the ice point is found experimentally to be 273.16°. The steam point therefore is 373.16° or 100° higher.

The *degree Kelvin* (°K) or degree of absolute temperature is the absolute unit of temperature and is, for practical purposes, identical with the degree Centigrade (°C) of the international temperature scale.

Thermodynamic Centigrade Scale. This is derived by subtracting from the Kelvin scale a constant number of the proper magnitude to make the ice point 0°. On this scale, therefore, the ice and steam points are 0 and 100°, respectively, and the so-called absolute zero is −273.16°.

International Centigrade Scale. This is a practical representation of the thermodynamic Centigrade scale to such a degree of accuracy as is possible with present-day apparatus and methods. It was adopted at the General Conference on Weights and Measures at Sèvres, France, in 1927 and is subject to revision and amendment as improved and more accurate methods of measurement are evolved.

The unit of temperature on the international scale is the *degree Centigrade* (°, or °C int) and is very nearly equal to $\frac{1}{100}$ the difference between the temperature of melting ice and the temperature of condensing water vapor under standard atmospheric pressure. (See discussion on metric units for pressure.)

The standard of the international temperature scale between −190 and +660°C is deduced from the electrical resistance of a standard platinum resistance thermometer by means of a formula connecting the resistance R_t at any temperature t°C within the above range with the resistance R_0 at 0°C. The purity of the platinum of which the thermometer is made should be such that the ratio R_t/R_0 for certain fixed temperatures is within specified limits. See also U.S. Bureau of Standards, *Journal of Research*, Vol. 1, p. 636, 1928.

The degree Centigrade is most widely used in scientific publications and increasingly also in the engineering literature. In many countries in Europe it is the common everyday temperature unit. The subdivision into a hundred degrees of the temperature interval between the ice point and the steam point was first used by Celsius, a German, in 1742; therefore, in the European literature "°C" is read "degree Celsius."

Fahrenheit Temperature Scale. This scale subdivides the temperature interval between the ice point and the steam point into 180 parts, one part of which is chosen as the unit of temperature and named *degree Fahrenheit* (°F). The ice point is assigned the value 32°F, so that the steam point has a temperature of 212°F.

The Fahrenheit unit of temperature is in common everyday use in the English-speaking countries. It was first introduced in England about 1665 by the physicist Fahrenheit; the choice of 32°F for the ice point has its explanation in the fact that Fahrenheit chose as zero the lowest temperature attainable by means of a salt–ice mixture.

Rankine Absolute Temperature Scale (°R). This is the thermodynamic Fahrenheit scale where absolute zero is 0°R (−459.69°F). The ice point is assigned the value 491.69°R and the steam point 671.69°R.

Relations between Temperature Scales. The following table shows the interrelations between the various temperature scales in the form of equations.

Temperature Interrelationships

$x°\mathrm{F} =$		$9/5(t°\mathrm{K} - 273.16) + 32$	$9/5(t°\mathrm{C}) + 32$
$x°\mathrm{K} =$	$5/9(t°\mathrm{F} - 32) + 273.16$		$(t°) + 273.16$
$x°\mathrm{C} =$	$5/9(t°\mathrm{F} - 32)$	$(t°\mathrm{K}) - 273.16$	
$x°\mathrm{R} =$	$(t°\mathrm{F}) + 459.699$	$9/5(t°\mathrm{K})$	$9/5(t°\mathrm{C}) + 491.69$

Here, X indicates the unknown number of chosen temperature units and t the known number of given temperature units:

Quantity of Heat and Some Derived Quantities

Units of Quantity of Heat. Quantity of heat is defined as the energy transferred from one body to another by a thermal process, that is, by radiation or conduction. The units for the quantity of heat are the *British thermal unit* and the *calorie* as specific thermal units and the *erg* and *joule* as general physical units (see discussion on units of energy, metric and English system of units).

Thermal Capacity or Specific Heat of a Substance. This is the quantity of heat required to produce a unit change in temperature in a unit of mass of the substance. The common English unit is the British thermal unit per degree Fahrenheit per pound mass (Btu per $^\circ$F per lb); the usual metric unit is the gram-calorie per degree Centigrade per gram mass (cal per $^\circ$C per g); and the general physical unit used in the scientific literature is the erg per degree Centigrade per gram mass (erg per $^\circ$C per g). In the technical literature thermal capacity of a substance is often expressed in watt-seconds (or joules) per degree Centigrade per kilogram mass (W-sec per $^\circ$C per kg) on account of the easy comparison with other technical units.

Calorimetric or Water Equivalent. This is the quantity of heat required to produce a unit change in temperature of a body or system. It is numerically equivalent to the mass of water (in units as involved in the definition of the unit of quantity of heat used) that could be raised a unit temperature by the same total quantity of heat. The thermal capacity is expressed in British thermal units per degree Fahrenheit (Btu per $^\circ$F), calories per degree Centigrade (cal per $^\circ$C), or watt-seconds per degree Centigrade (W-sec per $^\circ$C).

Thermal Conductivity. This is the time rate of heat transfer through a unit area across a unit thickness per unit difference in temperature between the end surfaces. It is measured in British thermal units per second per degree Fahrenheit per inch thickness per square inch cross section (Btu per sec per $^\circ$F per in. per in.^{2}), in calories per second per degree Centigrade per centimeter thickness per square centimeter cross section (cal per sec per $^\circ$C per cm per cm^2), or in watts per degree Centigrade per meter thickness per square meter cross section (W per $^\circ$C per m per m^2).

Thermal Transmittance. The surface coefficient of transfer is the time rate of heat emitted by a unit area for a unit difference in temperature between the surface in question and the surroundings. It is measured in British thermal units per second per degree Fahrenheit per square inch (Btu per sec per $^\circ$F per in.^{2}), in calories per second per degree Centigrade per square centimeter (cal per sec per $^\circ$C per cm^2), or in watts per degree Centigrade per square meter (Wa per $^\circ$C per m^2).

Joule Equivalent The **Joule equivalent** is defined as the number of foot-pounds of energy per Btu. The numerical values for the various energy units used in the English and metric systems are shown in the table below.

4.8 Chemical Units and Standards

Atomic Weight. The present definition of atomic weights (1961) is based on ^{12}C, which is the most abundant isotope of carbon and whose atomic weight is defined as exactly 12.

Standard Cell Potential. A very large class of chemical reactions are characterized by the transfer of protons or electrons. Substances losing electrons in a reaction are said to be oxidized, those gaining electrons are said to be reduced. Many such reactions can be carried out in a galvanic cell that forms a natural basis for the concept of the half-cell, that is, the overall cell is conceptually the sum of two half-cells, one corresponding to each electrode. The half-cell potential measures the tendency of one reaction, for example, oxidation, to proceed at its electrode; the other half-cell of the pair measures the corresponding tendency for reduction to proceed at the other electrode. Measurable cell potentials are the sum of the two half-cell potentials. Standard cell potentials refer to the tendency of reactants in their standard state to form products in their standard states. The standard conditions are 1 M concentration for solutions, 101.325 kPa (1 atm) for gases, and for solids, their most stable form at 25 $^\circ$C.

	Joules "Absolute"	Foot-pounds (force)	Foot-poundals	Meter-kilogram (force)	Kilowatt-hour "international"
1 British thermal unit (Btu) (mean) =	1055.18	778.26	25.040	107.599	2.93019×10^{-4}
1 gram-calorie (cal) (mean) =	4.1873	3.0884	99.366	0.42699	1.16279×10^{-6}
1 international kilocalorie (IT cal) =	4187.3	3088.4	99.366	426.99	1.16279×10^{-3}
1 Ostwald calorie =	418.73	308.84	9936.6	42.699	1.16279×10^{-4}

Since half-cell potentials cannot be measured directly, numerical values are obtained by assigning the hydrogen gas–hydrogen ion half reaction the half-cell potential of 0 V. Thus, by a series of comparisons referred directly or indirectly to the standard hydrogen electrode, values for the strength of a number of oxidants or reductants can be obtained, and standard reduction potentials can be calculated from established values.

Standard cell potentials are meaningful only when they are calibrated against an electromotive force (emf) scale. To achieve an absolute value of emf, electrical quantities must be referred to the basic metric system of mechanical units. If the current unit ampere and the resistance unit ohm can be defined, then the volt may be defined by Ohm's law as the voltage drop across a resistor of one standard ohm (Ω) when passing one standard ampere (A) of current. In the ohm measurement, a resistance is compared to the reactance of an inductor or capacitor at a known frequency. This reactance is calculated from the measured dimensions and can be expressed in terms of the meter and second. The ampere determination measures the force between two interacting coils while they carry the test current. The force between the coils is opposed by the force of gravity acting on a known mass; hence, the ampere can be defined in terms of the meter, kilogram, and second. Such a means of establishing a reference voltage is inconvenient for frequent use and reference is made to a previously calibrated standard cell.

Ideally, a standard cell is constructed simply and is characterized by a high constancy of emf, a low temperature coefficient of emf, and an emf close to 1 v. The Weston cell, which uses a standard cadmium sulfate electrolyte and electrodes of cadmium amalgam and a paste of mercury and mercurous sulfate, essentially meets these conditions. The voltage of the cell is 1.0183 V at 20 °C. The alternating current (ac) Josephson effect, which relates the frequency of a superconducting oscillator to the potential difference between two superconducting components, is used by the National Bureau of Standards to maintain the unit of emf, but the definition of the volt remains the Ω/A derivation described.

Concentration. The basic unit of concentration in chemistry is the mole, which is the amount of substance that contains as many entities, for example, atoms, molecules, ions, electrons, protons, and so on, as there are atoms in 12 g of ^{12}C, that is, Avogadro's number $N_A = 6.022045 \times 10^{23}$. Solution concentrations are expressed on either a weight or volume basis. *Molality* is the concentration of a solution in terms of the number of moles of solute per kilogram of solvent. *Molarity* is the concentration of a solution in terms of the number of moles of solute per liter of solution.

A particular concentration measure of acidity of aqueous solutions is pH, which, usually, is regarded as the common logarithm of the reciprocal of the hydrogen ion concentration (qv). More precisely, the potential difference of the hydrogen electrode in normal acid and in normal alkali solution (−0.828 V at 25 °C) is divided into 14 equal parts or pH units; each pH unit is 0.0591 V. Operationally, pH is defined by pH = pH (soln) + E/K, where E is the emf of the cell:

$$H_2|\text{solution of unknown pH}\|\text{saturated KCl}\|\ \text{solution of known pH}|H_2$$

and $K = 2.303\ RT/F$, where R is the gas constant, 8.314 J/(mol/K) [1.987 cal/(mol · K)], T is the absolute temperature, and F is the value of the Faraday, 9.64845×10^4C/mol. pH usually is equated to the negative logarithm of the hydrogen ion activity, although there are differences between these two quantities outside the pH range 4.0–9.2:

$$-\log q_{H^+} m_{H^+} = \begin{cases} \text{pH} + 0.014\ (\text{pH} - 9.2) & \text{for pH} > 9.2 \\ \text{pH} + 0.009\ (4.0 - \text{pH}) & \text{for pH} < 4.0 \end{cases}$$

4.9 Theoretical, or Absolute, Electrical Units

With the general adoption of SI as the form of metric system that is preferred for all applications, further use of cgs units of electricity and magnetism is deprecated. Nonetheless, for historical reasons as well as for comprehensiveness, a brief review is included in this section and section 4.10.

The definitions of the *theoretical*, or "*absolute,*" **units** are based on a particular choice of the numerical value of either k_e, the constant in Coulomb's, electrostatic force law, or k_m, the constant in Ampere's electrodynamic force law. The designation absolute units is generally used because of historical tradition; an interesting account of the history can be found in Glazebrook's *Handbook for Applied Physics*, Vol. II, "Electricity," pp. 211 ff., 1922. Because of the theoretical background of the unit definitions, they have also been designated as "theoretical" units, which is in good contradistinction to practical units based on physical standards.

Theoretical Electrostatic Units The *theoretical electrostatic units* are based on the cgs system of mechanical units and the choice of the numerical value unity for k_{ev} in Coulomb's law. They are frequently referred to as the *cgs electrostatic units*, but no specific unit names are available. In order to avoid the cumbersome writing, for example, one "theoretical electrostatic unit of charge," it had been proposed to use the theoretical "practical" unit names and prefix them with either stat or E.S. as, for example, statcoulomb, or E.S. coulomb. The first alternative will be used here.

The *absolute dielectric constant (permittivity)* of free space is the reciprocal of the Coulomb constant k_{ev} and is chosen as the fourth fundamental quantity in the theoretical electrostatic system of units. Its numerical value is defined as unity, and it is identical with one statfarad per centimeter if use is made of prefixing the corresponding unit of the "practical" series.

The theoretical electrostatic unit of *charge*, or the *statcoulomb*, is defined as the quantity of electricity that, when concentrated at a point and placed at one centimeter distance from an equal quantity of electricity similarly concentrated, will experience a mechanical force of one dyne in free space. An alternative definition, based on the concept of field lines, gives the theoretical electrostatic unit of charge as a positive charge from which in free space exactly 4π displacement lines emerge.

The theoretical electrostatic unit of *displacement flux (dielectric flux)* is the "line of displacement flux," or $\frac{1}{4}\pi$ of the theoretical electrostatic unit of charge. This definition provides the basis for graphical field mapping insofar as it gives a definite rule for the selection of displacement lines to represent the distribution of the field quantitatively.

The theoretical electrostatic unit of *displacement*, or *dielectric flux density*, is chosen as one displacement line per square centimeter area perpendicular to the direction of the displacement lines. It can be given also as $\frac{1}{4}\pi$ statcoulomb per square centimeter (according to Gauss's law). In isotropic media the displacement has the same direction as the potential gradient, and the surfaces perpendicular to the field lines become the equipotential surfaces; the theoretical electrostatic unit of displacement can then be defined as one displacement line per square centimeter of equipotential surface.

The theoretical electrostatic unit of *electrostatic potential*, or the *statvolt*, is defined as existing at a point in an electrostatic field, if the work done to bring the theoretical electrostatic unit of charge, or the statcoulomb, from infinity to this point equals one erg. This customary definition implies, however, that the potential vanishes at infinite distances and has, therefore, only restricted validity. As it is fundamentally impossible to give absolute values of potential, the use of potential difference and its unit (see below) should be preferred.

The theoretical electrostatic unit of *electrical potential difference* or *voltage*, is the *statvolt* and is defined as existing between two points in space if the work done to bring the theoretical electrostatic unit of charge, or the statcoulomb, from one of these points to the other equals one erg. Potential difference is counted positive in the direction in which a negative quantity of electricity would be moved by the electrostatic field.

The theoretical electrostatic unit of *capacitance*, or the *statfarad*, is defined as the capacitance that maintains an electrical potential difference of one statvolt between two conductors charged with equal and opposite electrical charges of one statcoulomb. In the older literature, the cgs electrostatic unit of capacitance is identified with the "centimeter"; this was replaced by statfarad to avoid confusion.

The theoretical electrostatic unit of *electric potential gradient*, or *field strength* (field intensity), is defined to exist at a point in an electric field if the mechanical force exerted upon the theoretical electrostatic unit of charge concentrated at this point is equal to one dyne. It is expressed as one statvolt per centimeter.

The theoretical electrostatic unit of *current*, or the *statampere*, is defined as the time rate of transfer of the theoretical electrostatic unit of charge and is identical with the statcoulomb per second.

The theoretical electrostatic unit of *electrical resistance*, or the *statohm*, is defined as the resistance of a conductor in which a current of one statampere is produced if a potential difference of one statvolt is applied at its ends.

The theoretical electrostatic unit of *electromotive force (emf)* is defined as equivalent to the theoretical electrostatic unit of potential difference if it produces a current of one statampere in a conductor of one statohm resistance. It is identical with the statvolt but, according to its concept, requires an independent definition.

The theoretical electrostatic unit of *magnetic intensity* is defined as the magnetic intensity at the center of a circle of 4π centimeters diameter in which a current of one statampere is flowing. This unit is equal to 4π statamperes per centimeter but has no name as the factor 4π excludes the possibility of using the prefixed "practical" unit name.

The theoretical electrostatic unit of *magnetic flux*, or the *statweben*, is defined as the magnetic flux whose time rate of change through a linear conductor loop (linear conductor is used to designate a conductor of infinitely small cross section) produces in this loop an emf of one statvolt.

The theoretical electrostatic unit of *magnetic flux density*, or *induction*, is defined as the electrostatic unit of magnetic flux per square centimeter area, or the statweber per square centimeter.

The *absolute magnetic permeability of free space* is defined as the ratio of magnetic induction to the magnetic intensity. Its unit is the stathenry per centimeter as a derived unit.

The theoretical electrostatic unit of *inductance*, or the *stathenry*, is defined as connected with a conductor loop carrying a steady current of one statampere that produces a magnetic flux of one statweber. A more general definition, applicable to varying fields with nonlinear relation between magnetic flux and current, gives the stathenry as connected with a conductor loop in which a time rate of change in the current of one statcoulomb produces a time rate of change in the magnetic flux of one statweber per second.

Theoretical Electromagnetic Units The *theoretical electromagnetic units* are based on the cgs system of mechanical units and Coulomb's law of mechanical force action between two isolated magnetic quantities m_1 and m_2 (approximately true for very long bar magnets) that must be written as

$$F_m = \frac{k_m}{2}\frac{m_1 m_2}{r^2} \tag{7}$$

where k_m is the proportionality constant of Ampere's law for force action between parallel currents that is more basic, and amenable to much more accurate measurement, than (7). The factor $\frac{1}{2}$ appears here because of the three-dimensional character of the field distribution around point magnets as compared with the two-dimensional field of two parallel currents.

The theoretical electromagnetic units are obtained by defining the numerical value of $k_{mv}/2$ (for vacuum) as unity; they are frequently referred to as the cgs electromagnetic units. Only a few specific unit names are available. In order to avoid cumbersome writing, for example, one "theoretical electromagnetic unit of charge," it had been proposed to use the theoretical "practical" unit names and prefix them with either ab- or E.M. as, for example, abcoulomb, or E.M. coulomb. The first alternative will be used here.

The *absolute magnetic permeability* of free space is the value $k_{mv}/2$ in (7) and is chosen as the fourth fundamental quantity in the theoretical electromagnetic system of units. Its numerical value is assumed as unity, and it is identical with one abhenry per centimeter if use is made of prefixing the corresponding unit of the "practical" series.

The theoretical electromagnetic unit of *magnetic quantity* is defined as the magnetic quantity that, when concentrated at a point and placed at one centimeter distance from an equal magnetic quantity similarly concentrated, will experience a mechanical force of one dyne in free space. An alternative definition, based on the concept of magnetic intensity lines, gives the theoretical electromagnetic unit of magnetic quantity as a positive magnetic quantity from which, in free space, exactly 4π magnetic intensity lines emerge.

The theoretical electromagnetic unit of *magnetic moment* is defined as the magnetic moment possessed by a magnet formed by two theoretical electromagnetic units of magnetic quantity of opposite sign, concentrated at two points one centimeter apart. As a vector, its positive direction is defined from the negative to the positive magnetic quantity along the center line.

The theoretical electromagnetic unit of *magnetic induction (magnetic flux density)*, or the *gauss*, is defined to exist at a point in a magnetic field, if the mechanical torque exerted upon a magnet with theoretical electromagnetic unit of magnetic moment and directed perpendicular to the magnetic field is equal to one dyne-centimeter. The lines to which the vector of magnetic induction is tangent at every point are called induction lines or magnetic flux lines; on the basis of this flux concept, magnetic induction is identical with magnetic flux density.

The theoretical electromagnetic unit of *magnetic flux*, or the *maxwell*, is the "field line" or line of magnetic induction. In free space, the theoretical electromagnetic unit of magnetic quantity issues 4π induction lines; the unit of magnetic flux, or the maxwell, is then $1/4\pi$ of the theoretical electromagnetic unit of magnetic quantity times the absolute permeability of free space.

The theoretical electromagnetic unit of *magnetic intensity (magnetizing force)*, or the *oersted*, is defined to exist at a point in a magnetic field in free space where one measures a magnetic induction of one gauss.

The theoretical electromagnetic unit of *current*, or the *abampere*, is defined as the current that flows in a circle of one centimeter diameter and produces at the center of this circle a magnetic intensity of one oersted.

The theoretical electromagnetic unit of *inductance*, or the *abhenry*, is defined as connected with a conductor loop in which a time rate of change of one maxwell per second in the magnetic flux produces a time rate of change in the current of one abampere per second. In the older literature, the cgs electromagnetic unit of inductance is identified with the "centimeter"; this should be replaced by a henry to avoid confusion.

The theoretical electromagnetic unit of *magnetomotive force (mmf)* is defined as the magnetic driving force produced by a conductor loop carrying a steady current of $\frac{1}{4}\pi$ abamperes; it has the name one gilbert. The concept of magnetomotive force as the driving force in a "magnetic circuit" permits an alternative definition of the gilbert as the magnetomotive force that produces a uniform magnetic intensity of one oersted over a length of one centimeter in the magnetic circuit. Obviously, one gilbert equals one oersted-centimeter.

The theoretical electromagnetic unit of *magnetostatic potential* is defined as the potential existing at a point in a magnetic field if the work done to bring the theoretical electromagnetic unit of magnetic quantity from infinity to this point equals one erg. This customary definition implies, however, that the potential vanishes at infinite distances, and the definition has therefore only restricted validity. The unit, thus defined, is identical with one gilbert. The difference in magnetostatic potential between any two points is usually called magnetomotive force (mmf).

The theoretical electromagnetic unit of *reluctance* is defined as the reluctance of a magnetic circuit in which a magnetomotive force of one gilbert produces a magnetic flux of one maxwell.

The theoretical electromagnetic unit of *electric charge*, or the *abcoulomb*, is defined as the quantity of electricity that passes through any section of an electric circuit in one second if the current is one abampere.

The theoretical electromagnetic unit of *displacement flux (dielectric flux)* is the "line of displacement flux," or $\frac{1}{4}\pi$ of the theoretical electromagnetic unit of electric charge. This definition provides the basis for graphical field mapping insofar as it gives a definite rule for the selection of displacement lines to represent the character of the field.

The theoretical electromagnetic unit of *displacement*, or *dielectric flux density*, is chosen as one displacement line per square centimeter area perpendicular to the direction of the displacement lines. It can also be given as $\frac{1}{4}\pi$ abcoulombs per square centimeter (according to Gauss's law). In isotropic media the theoretical electromagnetic unit of displacement can be defined as one displacement line per square centimeter of equipotential surface. (See discussion on theoretical electrostatic unit of displacement.)

The theoretical electromagnetic unit of *electrical potential difference*, or *voltage*, is the *abvolt* and is defined as the potential difference existing between two points in space if the work done in bringing the theoretical electromagnetic unit of charge, or the abcoulomb, from one of these points to the other equals one erg. Potential difference is counted positive in the direction in which a negative quantity of electricity would be moved by the electrostatic field.

The theoretical electromagnetic unit of *capacitance*, or the *abfarad*, is defined as the capacitance that maintains an electrical potential difference of one abvolt between two conductors charged with equal and opposite electrical quantities of one abcoulomb.

The theoretical electromagnetic unit of *potential gradient*, or *field strength* (field intensity), is defined to exist at a point in an electric field if the mechanical force exerted upon the theoretical electromagnetic unit of charge concentrated at this point is equal to one dyne. It is expressed as one abvolt per centimeter.

The theoretical electromagnetic unit of *resistance*, or the *abohm*, is defined as the resistance of a conductor in which a current of one abampere is produced if a potential difference of one abvolt is applied at its ends.

The theoretical electromagnetic unit of *electromotive force (emf)* is defined as the electromotive force acting in an electric circuit in which a current of one abampere is flowing and electrical energy is converted into other kinds of energy at the rate of one erg per second. This unit is identical with the abvolt.

The *absolute dielectric constant of free space* is defined as the ratio of displacement to the electric field intensity. Its unit is the abfarad per centimeter, a derived unit.

Theoretical Electrodynamic Units The theoretical electrodynamic units are based on the cgs system of mechanical units and are therefore frequently referred to as the *cgs electrodynamic units*. In contradistinction to the theoretical electromagnetic units, these units are derived from a significant experimental law, Ampere's experiment on the mechanical force between two parallel currents. The units as proposed by Ampere and used by W. Weber differ from the electromagnetic units by factors of 2 and multiples thereof. They can be made to coincide with the theoretical electromagnetic units by proper definition of the fundamental unit of current. Some of the important definitions will be given for this latter case only.

For the *absolute magnetic permeability* of free space, see discussion on theoretical electromagnetic units.

The theoretical electrodynamic unit of *current*, or the *abampere*, is defined as the current flowing in a circuit consisting of two infinitely long parallel wires one centimeter apart when the electrodynamic force of repulsion between the two wires is *two* dynes per centimeter length in free space. If the more natural choice of *one* dyne per centimeter length is made, the original proposal of Ampere is obtained and the unit of current becomes $1/\sqrt{2}$ abampere.

The theoretical electrodynamic unit of *magnetic induction* is defined as the magnetic induction inducing an electromotive force of one abvolt in a conductor of one centimeter length and moving with a velocity of one centimeter per second if the conductor, its velocity, and the magnetic induction are mutually perpendicular. The unit thus defined is called one gauss.

The theoretical electrodynamic unit of *magnetic flux*, or the *maxwell*, is defined as the magnetic flux represented by a uniform magnetic induction of one gauss over an area of one square centimeter perpendicular to the direction of the magnetic induction.

The theoretical electrodynamic unit of *magnetic intensity*, or the *oersted*, is defined as the magnetic intensity at the center of a circle of 4π centimeters diameter in which a current of one abampere is flowing.

All the other unit definitions, which do not pertain to magnetic quantities, are identical with the definitions for the theoretical electromagnetic units.

4.10 Internationally Adopted Electrical Units and Standards

In October 1946, at Paris, the International Committee on Weights and Measures decided to abandon the so-called international practical units based on physical standards (see below) and to adopt effective January 1, 1948, the so-called absolute practical units for international use.

Adopted Absolute Practical Units By a series of international actions, the "absolute" practical electrical units are defined as exact powers of 10 of corresponding theoretical electrodynamic and electromagnetic units because they are based on the choice of the proportionality constant in Ampère's law for free space as $k_{mv} = 2 \times 10^{-7}$ H/m

The *absolute practical unit of current*, or the absolute is defined as the current flowing in a circuit consisting of two very long parallel thin wires spaced 1 m apart in free space if the electrodynamic force action between the wires is 2×10^{-7} N = 0.02 dyne per meter length. It is 10^{-1} of the theoretical or absolute electrodynamic or electromagnetic unit of current and was adopted internationally in 1881.

The absolute practical unit of *electric charge*, or the *absolute coulomb*, is defined as the quantity of electricity that passes through a cross-sectional surface in one second if the current is one absolute ampere. It is 10^{-1} of the theoretical or absolute electromagnetic unit of electric charge and was adopted internationally in 1881.

The absolute practical unit of *electric potential difference*, or the *absolute volt*, is defined as the potential difference existing between two points in space if the work done in bringing an electric charge of one absolute coulomb from one of these points to another is equal to one absolute joule = 10^7 ergs. It is 10^8 of the theoretical or absolute electromagnetic unit of potential difference and was adopted internationally in 1881.

The absolute practical unit of *resistance*, or the *absolute ohm*, is defined as the resistance of a conductor in which a current of one absolute ampere is produced if a potential difference of one absolute volt is applied at its ends. It is 10^9 of the theoretical or absolute electromagnetic unit of resistance and was adopted internationally in 1881.

The absolute practical unit of *magnetic flux*, or the *absolute weber*, is defined to be linked with a closed loop of thin wire of total resistance one absolute ohm if upon removing the wire loop from the magnetic field a total charge of one absolute coulomb is passed through any cross section of the wire. It is 10^8 of the theoretical or absolute electromagnetic unit of magnetic flux, the maxwell, and was adopted internationally in 1933.

The absolute practical unit of *inductance*, or the *absolute henry*, is defined as connected with a closed loop of thin wire in which a time rate of change of one absolute weber per second in the magnetic flux produces a time rate of change in the current of one absolute ampere. It is 10^9 of the theoretical or absolute electromagnetic unit of inductance and was adopted internationally in 1893.

The absolute practical unit of *capacitance*, or the *absolute farad*, is defined as the capacitance that maintains an electric potential difference of one absolute volt between two conductors charged with equal and opposite electrical quantities of one coulomb. It is 10^{-9} of the theoretical or absolute electromagnetic unit of capacitance and was adopted internationally in 1881.

Abandoned International Practical Units The International System of electrical and magnetic units is a system for electrical and magnetic quantities that takes as the four fundamental quantities resistance, current, length, and time. The units of resistance and current are defined by physical standards that were originally aimed to be exact replicas of the "absolute" practical units, namely the absolute ampere and the absolute ohm. On account of long-range variations in the physical standards, it proved impossible to rely upon them for international use and they recently have been replaced by the absolute practical units.

The international practical standards are defined as follows:

The *international ohm* is the resistance at 0 °C of a column of mercury of uniform cross section having a length of 106.300 cm and a mass of 14.4521 g.

The *international ampere* is defined as the current that will deposit silver at the rate of 0.00111800 g/sec.

From these fundamental units, all other electrical and magnetic units can be defined in a manner similar to the absolute practical units. Because of the inconvenience of the silver voltameter as a standard, the various national laboratories actually used a volt, defining its value in terms of the other two standards.

At its conference in October 1946 in Paris, the International Committee on Weights and Measures accepted as the best relations between the international and the absolute practical units the following:

$$1 \text{ mean international ohm} = 1.00049 \text{ absolute ohms}$$

$$1 \text{ mean international volt} = 1.00034 \text{ absolute volts}$$

These mean values are the averages of values measured in six different national laboratories. On the basis of these mean values, the specific unit relation for converting international units appearing on certificates of the National Bureau of Standards, Washington, DC, into absolute practical units are as follows:

$$1 \text{ international ampere} = 0.999835 \text{ absolute ampere}$$

$$1 \text{ international coulomb} = 0.999835 \text{ absolute coulomb}$$

$$1 \text{ international henry} = 1.000495 \text{ absolute henries}$$

$$1 \text{ international farad} = 0.999505 \text{ absolute farad}$$

$$1 \text{ international watt} = 1.000165 \text{ absolute watts}$$

$$1 \text{ international joule} = 1.000165 \text{ absolute joules}$$

BIBLIOGRAPHY FOR UNITS AND MEASUREMENTS

Cohen, E. R., and Taylor, B. N., “The 1986 Adjustment of the Fundamental Physical Constants,” *Report of the CODATA Task Group on Fundamental Constants, November 1986*, CODATA Bulletin No. 63, International Council of Scientific Unions, Committee on Data for Science and Technology, Pergamon, 1986.

Hvistendahl, H. S., *Engineering Units and Physical Quantities*, Macmillan, London, 1964.

Jerrard, H. G., and McNeill, D. B., *A Dictionary of Scientific Units*, 2nd ed., Chapman & Hall, London, 1964.

Letter Symbols for Units of Measurement, ANSI/IEEE Std. 260-1978, Institute of Electrical and Electronic Engineers, New York, 1978.

Quantities, Units, Symbols, Conversion Factors, and Conversion Tables, ISO Reference 31, 15 sections, International Organization for Standardization Geneva, 1973–1979.

Standard for Metric Practice, ASTM E 380-82, American Society for Testing and Materials, Philadelphia, 1982.

Young, L., *System of Units in Electricity and Magnetism*, Oliver and Boyd, Edinburgh, 1969.

Young, L., *Research Concerning Metrology and Fundamental Constants*, National Academy Press, Washington, DC, 1983.

5 TABLES OF CONVERSION FACTORS*

J. G. Brainerd
(revised and extended by J. H. Westbrook)

Table 27 Temperature Conversion

$°F = (°C \times \frac{9}{5}) + 32 = (°C + 40) \times \frac{9}{5} - 40$
$°C = (°F - 32) \times \frac{5}{9} = (°F + 40) \times \frac{5}{9} - 40$
$°R = °F + 459.69$
$°K = C + 273.16$

*Boldface units in Tables 28–63 are SI.

Table 28 Length [L]

to Obtain ↓ \ Multiply Number of → by →	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

Length

Land Measure

7.92 inches = 1 link

25 links = 1 rod = 16.5 feet = 5.5 yards (1 rod = 1 pole = 1 perch)

4 rods = 1 chain (Gunther's) = 66 feet = 22 yards = 100 links

10 chains = 1 furlong = 660 feet = 220 yards = 1000 links = 40 rods

8 furlongs = 1 mile = 5280 feet = 1760 yards = 8000 links = 320 rods = 80 chains

Ropes and Cables

2 yards = 1 fathom   120 fathoms = 1 cable length

Nautical Measure

6080.27 feet = 1 nautical mile = 1.15156 statute miles

3 nautical miles = 1 league (U.S.) 3 statute miles = 1 league (Gr. Britain)

(*Note:* A nautical mile is the length of a minute of longitude of the earth at the equator at sea level. The British Admiralty uses the round figure of 6080 feet. The word "knot" is used to denote "nautical miles per hour.")

Miscellaneous

3 inches = 1 palm   9 inches = 1 span

4 inches = 1 hand $2\frac{1}{2}$ feet = 1 military pace

Table 29 Area [L^2]

to Obtain ↓ / Multiply Number of → by →	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

Area

Land Measure

$$30\tfrac{1}{4} \text{ square yards} = 1 \text{ square rod} = 272\tfrac{1}{4} \text{ square feet}$$

$$16 \text{ square rods} = 1 \text{ square chain} = 484 \text{ square yards} = 4356 \text{ square feet}$$

$$2\tfrac{1}{2} \text{ square chains} = 1 \text{ rood} = 40 \text{ square rods} = 1210 \text{ square yards}$$

$$4 \text{ roods} = 1 \text{ acre} = 10 \text{ square chains} = 160 \text{ square rods}$$

$$640 \text{ acres} = 1 \text{ square mile} = 2560 \text{ roods} = 102{,}400 \text{ square rods}$$

$$1 \text{ section of land} = 1 \text{ square mile; } 1 \text{ quarter section} = 160 \text{ acres}$$

Architect's Measure

$$100 \text{ square feet} = 1 \text{ square}$$

Circular Inch and Circular Mil A circular inch is the area of a circle 1 inch in diameter = 0.7854 square inch

$$1 \text{ square inch} = 1.2732 \text{ circular inches}$$

A circular mil is the area of a circle 1 mil (or 0.001 inch) in diameter = 0.7854 square mil

$$1 \text{ square mil} = 1.2732 \text{ circular mils}$$

$$1 \text{ circular inch} = 10^6 \text{ circular mils} = 0.7854 \times 10^6 \text{ square mils}$$

$$1 \text{ square inch} = 1.2732 \times 10^6 \text{ circular mils} = 10^6 \text{ square mils}$$

Table 30 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

Volume

Cubic Measure

1 cord of wood = pile cut 4 feet long piled 4 feet high and 8 feet on the ground
= 128 cubic feet

1 perch of stone = quantity $1\frac{1}{2}$ feet thick, 1 foot high, and $16\frac{1}{2}$ feet long
= $24\frac{3}{4}$ cubic feet

(*Note:* A perch of stone is, however, often computed differently in different localities; thus, in most if not all of the states west of the Mississippi, stonemasons figure rubble by the perch of $16\frac{1}{2}$ cubic feet. In Philadelphia, 22 cubic feet is called a perch. In Chicago, stone is measured by the cord of 100 cubic feet. Check should be made against local practice.)

Board Measure. In board measure, boards are assumed to be one inch in thickness. Therefore, feet board measure of a stick of square timber = length in feet × breadth in feet × thickness in inches.

Shipping Measure. For register tonnage or measurement of the entire internal capacity of a vessel, it is arbitrarily assumed, to facilitate computation, that

100 cubic feet = 1 register ton

For the measurement of cargo:

40 cubic feet = 1 U.S. shipping ton
= 32.143 U.S. bushels

42 cubic feet = 1 British shipping ton
= 32.703 Imperial bushels

Dry Measure. One U.S. Winchester bushel contains 1.2445 cubic feet or 2150.42 cubic inches. It holds 77.601 pounds distilled water at 62°F.

(*Note:* This is a *struck* bushel. A *heaped* bushel in general equals $1\frac{1}{4}$ struck bushels, although for apples and pears it contains 1.2731 struck bushels = 2737.72 cubic inches.)

One U. S. gallon (dry measure) = $\frac{1}{8}$ bushel and contains 268.8 cubic inches.

(*Note:* This is not a legal U.S. *dry measure* and therefore is given for comparison only.)

One British Imperial bushel contains 1.2843 cubic feet or 2219.36 cubic inches. It holds 80 pounds distilled water at 62°F.

1 British Imperial gallon = $\frac{1}{8}$ Imperial bushel and contains 277.42 cubic inches.

1 Winchester bushel = 0.9694 Imperial bushel

1 Imperial bushel = 1.032 Winchester bushels

Same relations as before maintain for gallons (dry measure).

[*Note:* 1 U.S. gallon (dry) = 1.164 U. S. gallons (liquid)).]

U.S. UNITS*

2 pints = 1 quart = 67.2 cubic inches
4 quarts = 1 gallon = 8 pints = 268.8 cubic inches
2 gallons = 1 peck = 16 pints = 8 quarts = 537.6 cubic inches
4 pecks = 1 bushel = 64 pints = 32 quarts = 8 gallons = 2150.42 cubic inches
1 cubic foot contains 6.428 gallons (dry measure)

Liquid Measure. One U.S. gallon (liquid measure) contains 231 cubic inches. It holds 8.336 pounds distilled water at 62°F.

One British Imperial gallon contains 277.42 cubic inches. It holds 10 pounds distilled water at 62°F.

1 U.S. gallon (liquid) = 0.8327 Imperial gallon

1 Imperial gallon = 1.201 U.S. gallons (liquid)

[*Note:* 1 U.S. gallon (liquid) = 0.8594 U.S. gallon (dry).]

U.S. UNITS

4 gills = 1 pint = 16 fluid ounces
2 pints = 1 quart = 8 gills = 32 fluid ounces
4 quarts = 1 gallon = 32 gills = 8 pints = 128 fluid ounces
1 cubic foot contains 7.4805 gallons (liquid measure)

Apothecaries' Fluid Measure

60 minims = 1 fluid drachm

8 drachms = 1 fluid ounce

In the United States a fluid ounce is the 128th part of a U.S. gallon, or 1.805 cubic inches or 29.58 cubic centimeters. It contains 455.8 grains of water at 62°F. In Great Britain the fluid ounce is 1.732 cubic inches and contains 1 ounce avoirdupois (or 437.5 grains) of water at 62°F.

*The *gallon* is not a U.S. legal *dry measure*.

Table 31 Plane Angle (No Dimensions)

Multiply Number of → by → to Obtain ↓	Degrees	Minutes	Quadrants	**Radians**[a]	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)	2.778×10^{-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° by definition.

Table 32 Solid Angle (No Dimensions)

Multiply Number of → by → to Obtain ↓	Hemispheres	Spheres[a]	Spherical Right Angles	**Steradians**[b]
Hemispheres	1	2	0.25	0.1592
Spheres[a]	0.5	1	0.125	7.958×10^{-2}
Spherical Right Angles	4	8	1	0.6366
Steradians[b]	6.283	12.57	1.571	1

[a] A sphere is the total solid angle about a point.
[b] 4π steradians = 1 sphere by definition.

Table 33 Time [*T*]

Multiply Number of → / by → / to Obtain ↓	Days	Hours	Minutes	Months (Average)[a]	**Seconds**	Weeks
Days	1	4.167×10^{-2}	6.944×10^{-4}	30.42	1.157×10^{-5}	7
Hours	24	1	1.667×10^{-2}	730.0	2.778×10^{-4}	168
Minutes	1440	60	1	4.380×10^{-4}	1.667×10^{-2}	1.008×10^{4}
Months (Average)[a]	3.288×10^{-2}	1.370×10^{-3}	2.283×10^{-5}	1	3.806×10^{-7}	0.2302
Seconds	8.64×10^{4}	3600	60	2.628×10^{6}	1	6.048×10^{5}
Weeks	0.1429	5.952×10^{-3}	9.921×10^{-5}	4.344	1.654×10^{-6}	1

[a]One common year = 365 days; one leap year = 366 days; one average month = $\frac{1}{12}$ of a common year.

Table 34 Linear Velocity [LT^{-1}]

to Obtain ↓ / by → / Multiply Number of →	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.

Linear Velocity

The Miner's Inch. The miner's inch is used in measuring flow of water. An act of the California legislature, May 23, 1901, makes the standard miner's inch 1.5 ft^3/ min, measured through any aperture or orifice.

The term miner's inch is more or less indefinite, for the reason that California water companies do not all use the same head above the center of the aperture, and the inch varies from 1.36 to 1.73 ft^3/min, but the most common measurement is through an aperture 2 in. high and whatever length is required and through a plank $1\frac{1}{4}$ in. thick. The lower edge of the aperture should be 2 in. above the bottom of the measuring box and the plank 5 in. high above the aperture, thus making a 6-in. head above the center of the stream. Each square inch of this opening represents a miner's inch, which is equal to a flow of 1.5 ft^3/ min.

Table 35 Angular Velocity [T^{-1}]

to Obtain ↓ / Multiply Number of → by →	Degrees per Second	**Radians per Second**	Revolutions per Minute	Revolutions per Second
Degrees per Second	1	57.30	6	360
Radians per Second	1.745×10^{-2}	1	0.1047	6.283
Revolutions per Minute	0.1667	9.549	1	60
Revolutions per Second	2.778×10^{-3}	0.1592	1.667×10^{-2}	1

Table 36 Linear Acceleration[a] [LT^{-2}]

to Obtain ↓ / Multiply Number of → by →	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

[a]The (standard) acceleration due to gravity (g_0) = 980.7 cm/sec sec, = 32.17 ft/sec sec = 35.30 km/hr sec = 9.807 m/sec sec = 21.94 mph/sec.

Table 37 Angular Acceleration [T^{-2}]

to Obtain ↓ / Multiply Number of → by →	**Radians per Second per Second**	Revolutions per Minute per Minute	Revolutions per Minute per Second	Revolutions per Second per Second
Radians per Second per Second	1	1.745×10^{-3}	0.1047	6.283
Revolutions per Minute per Minute	573.0	1	60	3600
Revolutions per Minute per Second	9.549	1.667×10^{-2}	1	60
Revolutions per Second per Second	0.1592	2.778×10^{-4}	1.667×10^{-2}	1

Table 38 Mass [*M*] and Weight[a]

to Obtain ↓ / by → / Multiply Number of →	Grains	Grams	**Kilograms**	Milligrams	Ounces[b]	Pounds[b]	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[b]	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[b]	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

[a] These same conversion factors apply to the *gravitational* units of force having the corresponding names. The dimensions of these units when used as gravitational units of force are MLT^{-2}; see Table 40.

[b] Avoirdupois pounds and ounces.

Table 39 Density or Mass per Unit Volume [ML^{-3}]

to Obtain ↓ / Multiply Number of → by ↘	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-sectional area.

Avoirdupois Weight. Used Commercially.

27.343 grains = 1 drachm
16 drachms = 1 ounce (oz) = 437.5 grains
16 ounces = 1 pound (lb) = 7000 grains
28 pounds = 1 quarter (qr)
4 quarters = 1 hundredweight (cwt)
= 112 pounds
20 hundredweight = 1 gross or long ton*
200 pounds = 1 net or short ton
14 pounds = 1 stone100 pounds
= 1 quintal

Troy Weight. Used in weighing gold or silver.

24 grains = 1 pennyweight (dwt)
20 pennyweights = 1 ounce (oz) = 480 grains
12 ounces = 1 pound (lb) = 5760 grains

The grain is the same in avoirdupois, troy, and apothecaries' weights. A carat, for weighing diamonds, = 3.086 grains = 0.200 gram (International Standard, 1913.)

1 pound troy = 0.8229 pound avoirdupois
1 pound avoirdupois = 1.2153 pounds troy

Apothecaries' Weight. Used in compounding medicines.

20 grains = 1 scruple()
3 scruples = 1 drachm() = 60 grains
8 drachms = 1 ounce() = 480 grains
12 ounces = 1 pound(lb) = 5760 grains

The grain is the same in avoirdupois, troy, and apothecaries' weights.

1 pound apothecaries = 0.82286 pound avoirdupois
1 pound avoirdupois = 1.2153 pounds apothecaries

*The long ton is used by the U.S. custom houses in collecting duties upon foreign goods. It is also used in freighting coal and selling it wholesale.

Table 40 Force[a] $[MLT^{-2}]$ 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

[a] Conversion factors between absolute and gravitational units apply only under standard acceleration due to gravity conditions. (See Section 4.)

Table 41 Pressure or Force per Unit Area $[ML^{-1}T^{-2}]$ or $[FL^{-2}]$

To Obtain ↓ / Multiply Number of → by →	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	9.869×10^{-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^{-8}
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}	2.491×10^{-4}	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, p. 68.

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

Table 42 Torque or Moment of Force [ML^2T^{-2}] or [FL][a]

Multiply Number of → by ↘ to Obtain ↓	Dyne-Centimeters	Gram-Centimeters	Kilogram-Meters	Pound-Feet	**Newton-Meter**
Dyne-Centimeters	1	980.7	9.807×10^7	1.356×10^7	10^7
Gram-Centimeters	1.020×10^{-3}	1	10^5	1.383×10^4	1.020×10^4
Kilogram-Meters	1.020×10^{-8}	10^{-5}	1	0.1383	0.1020
Pound-Feet	7.376×10^{-8}	7.233×10^{-5}	7.233	1	0.7376
Newton-Meter	10^{-7}	9.807×10^{-4}	9.807	1.356	1

[a]Same dimensions as energy; more properly torque should be expressed as newton-meters per radian to avoid this confusion.

Table 43 Moment of Inertia [ML^2]

Multiply Number of → by ↘ to Obtain ↓	Gram-Centimeters Squared	**Kilogram-Meters Squared**	Pound-Inches Squared	Pound-Feet Squared	Slug-Feet Squared
Gram-Centimeters Squared	1	10^7	2.9266×10^3	4.21434×10^5	1.3559×10^7
Kilogram-Meters Squared	10^{-7}	1	2.9266×10^{-4}	4.21434×10^{-2}	1.3559
Pound-Inches Squared	3.4169×10^{-4}	3.4169×10^3	1	144	4.63304×10^3
Pound-Feet Squared	2.37285×10^{-6}	23.7285	6.944×10^{-3}	1	32.1739
Slug-Feet Squared	7.37507×10^{-8}	0.737507	2.15841×10^{-4}	3.10811×10^{-2}	1

Table 44 Energy, Work and Heat[a] $[ML^2T^{-2}]$ or $[FL]$

Multiply Number of → by → to Obtain ↓	British Thermal Units[b]	Centimeter-Grams	Ergs or Centimeter-Dynes	Foot-Pounds	Horsepower-Hours	**Joules,**[c] or Watt-Seconds	Kilogram-Calories[b]	Kilowatt-Hours	Meter-Kilograms	Watt-Hours
British Thermal Units[b]	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,[c] 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[b]	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	2.778×10^{-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

[a] See note at the bottom of Table 45.
[b] 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 kilowatthour (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.
[c] Absolute joule, defined as 10^7 ergs. The international joule, based on the international ohm and ampere, equals 1.0003 absolute joules.

Table 45 Power or Rate of Doing Work[a] $[ML^2T^{-3}]$ 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[a]	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[a]	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	1.758×10^{-2}	10^{-10}	2.260×10^{-5}	1.356×10^{-3}	0.7457	6.977×10^{-2}	1	0.7355	10^{-3}
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

Note:

1 Cheval-vapeur = 75 kilogram-meters per second

1 Poncelet = 100 kilogram-meters per second

[a]The ''horsepower'' used in these tables 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.

Table 46 Quantity of Electricity and Dielectric Flux *[Q]*

Multiply Number of → by → to Obtain ↓	Abcoulombs	Ampere-Hours	**Coulombs**	Faradays	Stat coulombs
Abcoulombs	1	360	0.1	9649	3.335×10^{-11}
Ampere-Hours	2.778×10^{-3}	1	2.778×10^{-4}	26.80	9.259×10^{-14}
Coulombs	10	3600	1	9.649×10^{4}	3.335×10^{-10}
Faradays	1.036×10^{-4}	3.731×10^{-2}	1.036×10^{-5}	1	3.457×10^{-15}
Statcoulombs	2.998×10^{10}	1.080×10^{13}	2.998×10^{9}	2.893×10^{14}	1

Table 47 Charge per Unit Area and Electric Flux Density [QL^{-2}]

Multiply Number of → by → to Obtain ↓	Abcoulombs per Square Centimeter	Coulombs per Square Centimeter	Coulombs per Square Inch	Statcoulombs per Square Centimeter	**Coulombs per Square Meter**
Abcoulombs per Square Centimeter	1	0.1	1.550×10^{-2}	3.335×10^{-11}	10^{-5}
Coulombs per Square Centimeter	10	1	0.1550	3.335×10^{-10}	10^{-4}
Coulombs per Square Inch	64.52	6.452	1	2.151×10^{-9}	6.452×10^{-4}
Statcoulombs per Square Centimeter	2.998×10^{10}	2.998×10^{9}	4.647×10^{8}	1	2.998×10^{5}
Coulombs per Square Meter	10^{5}	10^{4}	1550	3.335×10^{-6}	1

Table 48 Electric Current [QT^{-1}]

Multiply Number of → by → to Obtain ↓	Abamperes	**Amperes**	Statamperes
Abamperes	1	0.1	3.335×10^{-11}
Amperes	10	1	3.335×10^{-10}
Statamperes	2.998×10^{10}	2.998×10^{9}	1

Table 49 Current Density [$QT^{-1}L^{-2}$]

to Obtain ↓ / Multiply Number of → by ↘	Abamperes per Square Centimeter	Amperes per Square Centimeter	Amperes per Square Inch	Statamperes per Square Centimeter	**Amperes per Square Meter**
Abamperes per Square Centimeter	1	0.1	1.550×10^{-2}	3.335×10^{-11}	10^{-5}
Amperes per Square Centimeter	10	1	0.1550	3.335×10^{-10}	10^{-4}
Amperes per Square Inch	64.52	6.452	1	2.151×10^{-9}	6.452×10^{-4}
Statamperes per Square Centimeter	2.998×10^{10}	2.998×10^{9}	4.647×10^{8}	1	2.998×10^{5}
Amperes per Square Meter	10^{5}	10^{4}	1550	3.335×10^{-6}	1

Table 50 Electric Potential and Electromotive Force [$MQ^{-1}L^{2}T^{-2}$] or [$FQ^{-1}L$]

to Obtain ↓ / Multiply Number of → by ↘	Abvolts	Microvolts	Millivolts	Statvolts	**Volts**
Abvolts	1	100	10^{5}	2.998×10^{10}	10^{8}
Microvolts	0.01	1	1000	2.998×10^{8}	10^{6}
Millivolts	10^{-5}	0.001	1	2.998×10^{5}	1000
Statvolts	3.335×10^{-11}	3.335×10^{-9}	3.335×10^{-6}	1	3.335×10^{-3}
Volts	10^{-8}	10^{-6}	0.001	299.8	1

Table 51 Electric Field Intensity and Potential Gradient [$MQ^{-1}LT^{-2}$] or [FQ^{-1}]

Multiply Number of → by → to Obtain ↓	Abvolts per Centimeter	Microvolts per Meter	Millivolts per Meter	Statvolts per Centimeter	Volts per Centimeter	Kilovolts per Centimeter	Volts per Inch	Volts per Mil	**Volts per Meter**
Abvolts per Centimeter	1	1	1000	2.998×10^{10}	10^8	10^{11}	3.937×10^7	3.937×10^{10}	10^6
Microvolts per Meter	1	1	1000	2.998×10^{10}	10^8	10^{11}	3.937×10^7	3.937×10^{10}	10^6
Millivolts per Meter	0.001	0.001	1	2.998×10^7	10^5	10^8	3.937×10^4	3.937×10^7	1000
Statvolts per Centimeter	3.335×10^{-11}	3.335×10^{-11}	3.335×10^{-8}	1	3.335×10^{-3}	3.335	1.313×10^{-3}	1.313	3.335×10^{-5}
Volts per Centimeter	10^{-8}	10^{-8}	10^{-5}	299.8	1	1000	0.3937	393.7	10^{-2}
Kilovolts per Centimeter	10^{-11}	10^{-11}	10^{-8}	0.2998	0.001	1	3.937×10^{-4}	0.3937	10^{-5}
Volts per Inch	2.540×10^{-8}	2.540×10^{-8}	2.540×10^{-5}	761.6	2.540	2540	1	1000	2.540×10^{-2}
Volts per Mil	2.540×10^{-11}	2.540×10^{-11}	2.540×10^{-8}	0.7616	2.540×10^{-3}	2.540	0.001	1	2.540×10^{-5}
Volts per Meter	10^{-6}	10^{-6}	10^{-3}	2.998×10^4	100	10^5	39.37	3.937×10^4	1

Table 52 Electric Resistance $[MQ^{-2}L^2T^{-1}]$ or $[FQ^{-2}LT]$

Multiply Number of → by → to Obtain ↓	Abohms	Megohms	Microhms	**Ohms**	Statohms
Abohms	1	10^{15}	1000	10^9	8.988×10^{20}
Megohms	10^{-15}	1	10^{-12}	10^{-6}	8.988×10^5
Microhms	0.001	10^{12}	1	10^6	8.988×10^{17}
Ohms	10^{-9}	10^6	10^{-6}	1	8.988×10^{11}
Statohms	1.112×10^{-21}	1.112×10^{-6}	1.112×10^{-18}	1.112×10^{-12}	1

Note: Electric Conductance $[F^{-1}Q^2L^{-1}T^{-1}]$. 1 Siemens = 1 mho = 1 ohm^{-1} = 10^{-6} megmho = 10^6 micromho.

Table 53 Electric Resistivity[a] $[MQ^{-2}L^3T^{-1}]$ or $[FQ^{-2}L^2T]$

Multiply Number of → by → to Obtain ↓	Abohm-Centimeters	Microhm-Centimeters	Microhm-Inches	Ohms (Mil, Foot)	Ohms (Meter, Gram)[b]	**Ohm-Meters**
Abohm-Centimeters	1	1000	2540	166.2	$10^5/\delta$	10^{11}
Microhm-Centimeters	0.001	1	2.540	0.1662	$100/\delta$	10^8
Microhm-Inches	3.937×10^{-4}	0.3937	1	6.545×10^{-2}	$39.37/\delta$	3.937×10^7
Ohms (Mil, Foot)	6.015×10^{-3}	6.015	15.28	1	$601.5/\delta$	6.015×10^8
Ohms (Meter, Gram)[b]	$10^{-5}\delta$	0.01δ	$2.540 \times 10^{-2}\delta$	$1.662 \times 10^{-3}\delta$	1	$10^{-6}\delta$
Ohm-Meters	10^{-11}	10^{-8}	2.540×10^{-8}	1.662×10^{-9}	$10^{-6}/\delta$	1

[a] In this table δ is density in grams per cubic-centimeters. The following names, corresponding respectively to those at the tops of columns, are sometimes used: abohms per centimeter cube; microhms per centimeter cube; microhms per inch cube; ohms per milfoot; ohms per meter-gram. The first four columns are headed by units of *volume* resistivity, the last by a unit of *mass* resistivity. The dimensions of the latter are $Q^{-2}L^6T^{-1}$, not those given in the heading of the table.
[b] One ohm (meter, gram) = 5710 ohms (mile, pound).

Table 54 Electric Conductivity[a] $[M^{-1}Q^2L^{-3}T]$ or $[F^{-1}Q^2L^{-2}T^{-1}]$

Multiply Number of → by → to Obtain ↓	Abmhos per Centimeter	Mhos (Mil, Foot)	Mhos (Meter, Gram)	Micromhos per Centimeter	Micromhos per Inch	**Siemens per Meter**
Abmhos per Centimeter	1	6.015×10^{-3}	$10^{-5}\delta$	0.001	3.937×10^{-4}	10^{-11}
Mhos (Mil, Foot)	166.2	1	$1.662 \times 10^{-3}\delta$	0.1662	6.524×10^{-2}	1.662×10^{-9}
Mhos (Meter, Gram)	$10^5/\delta$	$601.5/\delta$	1	$100/\delta$	$39.37/\delta$	$10^{-6}/\delta$
Micromhos per Centimeter	1000	6.015	0.01δ	1	0.3937	10^{-8}
Micromhos per Inch	2540	15.28	$2.540 \times 10^{-2}\delta$	2.540	1	2.54×10^{-8}
Siemens per Meter	10^{11}	6.015×10^8	$10^6\delta$	10^8	3.937×10^7	1

[a] See footnote of Table 53. Names sometimes used are abmho per centimeter cube, mho per mil-foot, etc. Dimensions of mass conductivity are $Q^2L^{-6}T$.

Table 55 Capacitance [$M^{-1}Q^2L^{-2}T^2$] or [$F^{-1}Q^2L^{-1}$]

Multiply Number of → by ↘ to Obtain ↓	Abfarads	**Farads**	Microfarads	Statfarads
Abfarads	1	10^{-9}	10^{-15}	1.112×10^{-21}
Farads	10^9	1	10^{-6}	1.112×10^{-12}
Microfarads	10^{15}	10^6	1	1.112×10^{-6}
Statfarads	8.988×10^{20}	8.988×10^{11}	8.988×10^5	1

Table 56 Inductance [$MQ^{-2}L^2$] or [$FQ^{-2}LT^2$]

Multiply Number of → by ↘ to Obtain ↓	Abhenries[a]	**Henries**	Microhenries	Millihenries	Stathenries
Abhenries[a]	1	10^9	1000	10^6	8.988×10^{20}
Henries	10^{-9}	1	10^{-6}	0.001	8.988×10^{11}
Microhenries	0.001	10^6	1	1000	8.988×10^{17}
Millihenries	10^{-6}	1000	0.001	1	8.988×10^{14}
Stathenries	1.112×10^{-21}	1.112×10^{-12}	1.112×10^{-18}	1.112×10^{-15}	1
					1

[a] An abhenry is sometimes called a ‘‘centimeter.’’

Table 57 Magnetic Flux [$MQ^{-1}L^2T^{-1}$] or [$FQ^{-1}LT$]

Multiply Number of → by ↘ to Obtain ↓	Kilolines	Maxwells (or Lines)	Webers
Kilolines	1	0.001	10^5
Maxwells (or Lines)	1000	1	10^8
Webers	10^{-5}	10^{-8}	1

Table 58 Magnetic Flux Density [$MQ^{-1}T^{-1}$] or [$FQ^{-1}L^{-1}T$]

to Obtain ↓ / by ↘ / Multiply Number of →	Gausses (or Lines per Square Centimeter)	Lines per Square Inch	Webers per Square Centimeter	Webers per Square Inch	**Tesla** (Webers per Square Meter)
Gausses (or Lines per Square Centimeter)	1	0.1550	10^8	1.550×10^7	10^4
Lines per Square Inch	6.452	1	6.452×10^8	10^8	6.452×10^4
Webers per Square Centimeter	10^{-8}	1.550×10^{-9}	1	0.1550	10^{-4}
Webers per Square Inch	6.452×10^{-8}	10^{-8}	6.452	1	6.452×10^{-4}
Tesla (Webers per Square Meter)	10^{-4}	1.550×10^{-5}	10^4	1550	1

Table 59 Magnetic Potential and Magnetomotive Force [QT^{-1}]

to Obtain ↓ / by ↘ / Multiply Number of →	Abampere-Turns	**Ampere-Turns**	Gilberts
Abampere-Turns	1	0.1	7.958×10^{-2}
Ampere-Turns	10	1	0.7958
Gilberts	12.57	1.257	1

Table 60 Magnetic Field Intensity, Potential Gradient, and Magnetizing Force [$QL^{-1}T^{-1}$]

to Obtain ↓ / by ↘ / Multiply Number of →	Abampere-Turns per Centimeter	Ampere-Turns per Centimeter	Ampere-Turns per Inch	Oersteds (Gilberts per Centimeter)	**Ampere-Turns per Meter**
Abampere-Turns per Centimeter	1	0.1	3.937×10^{-2}	7.958×10^{-2}	10^{-3}
Ampere-Turns per Centimeter	10	1	0.3937	0.7958	10^{-2}
Ampere-Turns per Inch	25.40	2.540	1	2.021	2.54×10^{-2}
Oersteds (Gilberts per Centimeter)	12.57	1.257	0.4950	1	1.257×10^{-2}
Ampere-Turns per Meter	10^3	10^2	39.37	79.58	1

Table 61 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 formulas:

$$t_c = \text{temperature in Centigrade degrees}$$

$$t_f = \text{temperature in Fahrenheit degrees}$$

$$t_{\mathrm{K}} = \text{temperature in Kelvin degrees}$$

$$1\ \mathrm{F} = \tfrac{5}{9}{}^\circ\mathrm{C}$$

$$1\ \mathrm{K} = 1^\circ\mathrm{C}$$

$$t_c = \tfrac{5}{9}(t_f - 32)$$

$$t_f = \tfrac{9}{5}t_c + 32$$

$$t_{\mathrm{K}} = t_c + 273$$

Table 62 Thermal Conductivity[a] [$LMT^{-3}t^{-1}$]

Multiply Number of → by → to Obtain ↓	Btu · ft/h · ft^2 · °F	Btu · in./h · ft^2 · °F	Btu · in./sec · ft^2 · °F	J/m · s · °C	kcal/m · h · °C	erg/cm · s · °C	kcal/m · s · °C	cal/cm · s · °C	W/ft · °C	W/m · K
Btu · ft/h · ft^2 · °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./h · ft^2 · °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./s · ft^2 · °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}
J/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/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/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/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/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/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/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

[a] International Table Btu $= 1.055056 \times 10^{3}$ joules and International Table cal $= 4.1868$ J are used throughout.

Table 63 Photometric Units

	Common Unit	Multiply by	to Get **SI Unit**
Luminous intensity	International candle	9.81×10^{-1}	**cd**
Luminance	cd/in.^{2}	1.550×10^3	**cd/m^2**
	cd/cm^2	1×10^4	**cd/m^2**
	Foot · lambert	3.4263	**cd/m^2**
Luminous flux	cd · sr	1.0000	**lm**
	Candle power (spher.)	12.566	**lm**
Quantity of light flux			**lm·**
Luminous exitance[a]			**lm/m^2**
Illuminance[b]	lm	3.103×10^3	**cd/m^2**
	Foot candles	1.0764×10	**lm/m^2**
	lmft^2	1.0764×10	**lm/m^2**
	lx	1.000	**lm/m^2**
	Phots	1×10^4	**lm/m^2**
Luminous efficacy			**lm/W**

[a] Luminous emittance.
[b] Luminous flux density.

Table 64 Specific Gravity Conversions

Specific Gravity 60°/60°	°Be	°API	lb/gal 60°F, wt in air	lb/ft^3 at 60°F, wt in air	Specific Gravity 60°/60°	°Be	°API	lb/gal 60°F, wt in air	lb/ft^3 at 60°F, wt in air
0.600	103.33	104.33	4.9929	37.350	0.745	57.92	58.43	6.2020	46.394
0.605	101.40	102.38	5.0346	37.662	0.750	56.67	57.17	6.2437	46.706
0.610	99.51	100.47	5.0763	37.973	0.755	55.43	55.92	6.2854	47.018
0.615	97.64	98.58	5.1180	38.285	0.760	54.21	54.68	6.3271	47.330
0.620	95.81	96.73	5.1597	38.597	0.765	53.01	53.47	6.3688	47.642
0.625	94.00	94.90	5.2014	39.910	0.770	51.82	52.27	6.4104	47.953
0.630	92.22	93.10	5.2431	39.222	0.775	50.65	51.08	6.4521	48.265
0.635	90.47	91.33	5.2848	39.534	0.780	49.49	49.91	6.4938	48.577
0.640	88.75	89.59	5.3265	39.845	0.785	48.34	48.75	6.5355	48.889
0.645	87.05	87.88	5.3682	40.157	0.790	47.22	47.61	6.5772	49.201
0.650	85.38	86.19	5.4098	40.468	0.795	46.10	46.49	6.6189	49.513
0.655	83.74	84.53	5.4515	40.780	0.800	45.00	45.38	6.6606	49.825
0.660	82.12	82.89	5.4932	41.092	0.805	43.91	44.28	6.7023	50.137
0.665	80.53	81.28	5.5349	41.404	0.810	42.84	43.19	6.7440	50.448
0.670	78.96	79.69	5.5766	41.716	0.815	41.78	42.12	6.7857	50.760
0.675	77.41	78.13	5.6183	42.028	0.820	40.73	41.06	6.8274	51.072
0.680	75.88	76.59	5.6600	42.340	0.825	39.70	40.02	6.8691	51.384
0.685	74.38	75.07	5.7017	42.652	0.830	38.67	38.98	6.9108	51.696
0.690	72.90	73.57	5.7434	42.963	0.835	37.66	37.96	6.9525	52.008
0.695	71.44	72.10	5.7851	43.275	0.840	36.67	36.95	6.9941	52.320
0.700	70.00	70.64	5.8268	43.587	0.845	35.68	35.96	7.0358	52.632
0.705	68.58	69.21	5.8685	43.899	0.850	34.71	34.97	7.0775	52.943
0.710	67.18	67.80	5.9101	44.211	0.855	33.74	34.00	7.1192	53.225
0.715	65.80	66.40	5.9518	44.523	0.860	32.79	33.03	7.1609	53.567
0.720	64.44	65.03	5.9935	44.834	0.865	31.85	32.08	7.2026	53.879
0.725	63.10	63.67	6.0352	45.146	0.870	30.92	31.14	7.2443	54.191
0.730	61.78	62.34	6.0769	45.458	0.875	30.00	30.21	7.2860	54.503
0.735	60.48	61.02	6.1186	45.770	0.880	29.09	29.30	7.3277	54.815
0.740	59.19	59.72	6.1603	46.082	0.885	28.19	28.38	7.3694	55.127

(*Continues*)

Table 64 (*Continued*)

Specific Gravity 60°/60°	°Be	°TW	lb/gal 60°F, wt in air	lb/ft^3 at 60°F, wt in air
0.890	27.30	27.49	7.4111	55.438
0.895	26.42	26.60	7.4528	55.750
0.900	25.76	25.72	7.4944	56.062
0.905	24.70	24.85	7.5361	56.374
0.910	23.85	23.99	7.5777	56.685
0.915	23.01	23.14	7.6194	56.997
0.920	22.17	22.30	7.6612	57.410
0.925	21.35	21.47	7.7029	57.622
0.930	20.54	20.65	7.7446	57.934
0.935	19.73	19.84	7.7863	58.246
0.940	18.94	19.03	7.8280	58.557
0.945	18.15	18.24	7.8697	58.869
0.950	17.37	17.45	7.9114	59.181
0.955	16.60	16.67	7.9531	59.493
0.960	15.83	15.90	7.9947	59.805
0.965	15.08	15.13	8.0364	60.117
0.970	14.33	14.38	8.0780	60.428
0.975	13.59	13.63	8.1197	60.740
0.980	12.86	12.89	8.1615	61.052
0.985	12.13	12.15	8.2032	61.364
0.990	11.41	11.43	8.2449	61.676
0.995	10.70	10.71	8.2866	61.988
1.000	10.00	10.00	8.3283	62.300
1.005	0.72	1	8.3700	62.612
1.010	1.44	2	8.4117	62.924
1.015	2.14	3	8.4534	63.236
1.020	2.84	4	8.4950	63.547
1.025	3.54	5	8.5367	63.859
1.030	4.22	6	8.5784	64.171
1.035	4.90	7	8.6201	64.483
1.040	5.58	8	8.6618	64.795
1.045	6.24	9	8.7035	65.107
1.050	6.91	10	8.7452	65.419
1.055	7.56	11	8.7869	65.731
1.060	8.21	12	8.8286	66.042
1.065	8.85	13	8.8703	66.354
1.070	9.49	14	8.9120	66.666
1.075	10.12	15	8.9537	66.978
1.080	10.74	16	8.9954	67.290
1.085	11.36	17	9.0371	67.602
1.090	11.97	18	9.0787	67.914
1.095	12.58	19	9.1204	68.226
1.100	13.18	20	9.1621	68.537
1.105	13.78	21	9.2038	68.849
1.110	14.37	22	9.2455	69.161
1.115	14.96	23	9.2872	69.473
1.120	15.54	24	9.3289	69.785
1.125	16.11	25	9.3706	70.097
1.130	16.68	26	9.4123	70.409
1.135	17.25	27	9.4540	70.721
1.140	17.81	28	9.4957	71.032
1.145	18.36	29	9.5374	71.344
1.150	18.91	30	9.5790	71.656
1.155	19.46	31	9.6207	71.968
1.160	20.00	32	9.6624	72.280
1.165	20.54	33	9.7041	72.592
1.170	21.07	34	9.7458	72.904
1.175	21.60	35	9.7875	73.216
1.180	22.12	36	9.8292	73.528
1.185	22.64	37	9.8709	73.840
1.190	23.15	38	9.9126	74.151
1.195	23.66	39	9.9543	74.463
1.200	24.17	40	9.9960	74.775
1.205	24.67	41	10.0377	75.087
1.210	25.17	42	10.0793	75.399
1.215	25.66	43	10.1210	75.711
1.220	26.15	44	10.1627	76.022
1.225	26.63	45	10.2044	76.334
1.230	27.11	46	10.2461	76.646
1.235	27.59	47	10.2878	76.958
1.240	28.06	48	10.3295	77.270
1.245	28.53	49	10.3712	77.582
1.250	29.00	50	10.4129	77.894
1.255	29.46	51	10.4546	78.206
1.260	29.92	52	10.4963	78.518
1.265	30.38	53	10.5380	78.830
1.270	30.83	54	10.5797	79.141
1.275	31.27	55	10.6214	79.453
1.280	31.72	56	10.6630	79.765
1.285	32.16	57	10.7047	80.077
1.290	32.60	58	10.7464	80.389
1.295	33.03	59	10.7881	80.701
1.300	33.46	60	10.8298	81.013
1.305	33.89	61	10.8715	81.325
1.310	34.31	62	10.9132	81.636
1.315	34.73	63	10.9549	81.948
1.320	35.15	64	10.9966	82.260
1.325	35.57	65	11.0383	82.572
1.330	35.98	66	11.0800	82.884
1.335	36.39	67	11.1217	83.196
1.340	36.79	68	11.1634	83.508
1.345	37.19	69	11.2051	83.820
1.350	37.59	70	11.2467	84.131
1.355	37.99	71	11.2884	84.443
1.360	38.38	72	11.3301	84.755
1.365	38.77	73	11.3718	85.067
1.370	39.16	74	11.4135	85.379
1.375	39.55	75	11.4552	85.691
1.380	39.93	76	11.4969	86.003
1.385	40.31	77	11.5386	86.315
1.390	40.68	78	11.5803	86.626
1.395	41.06	79	11.6220	86.938
1.400	41.43	80	11.6637	87.250
1.405	41.80	81	11.7054	87.562
1.410	42.16	82	11.7471	87.874

Table 64 (*Continued*)

Specific Gravity 60°/60°	°Be	°TW	lb/gal 60°F, wt in air	lb/ft^3 at 60°F, wt in air	Specific Gravity 60°/60°	°Be	°TW	lb/gal 60°F, wt in air	lb/ft^3 at 60°F, wt in air
1.415	42.53	83	11.7888	88.186	1.67	58.17	134	13.915	104.09
1.420	42.89	84	11.8304	88.498	1.68	58.69	136	13.998	104.72
1.425	43.25	85	11.8721	88.810	1.69	59.20	138	14.082	105.34
1.430	43.60	86	11.9138	89.121	1.70	59.71	140	14.165	105.96
1.435	43.95	87	11.9555	89.433	1.71	60.20	142	14.249	106.59
1.440	44.31	88	11.9972	89.745	1.72	60.70	144	14.332	107.21
1.445	44.65	89	12.0389	90.057	1.73	61.18	146	14.415	107.83
1.450	45.00	90	12.0806	90.369	1.74	61.67	148	14.499	108.46
1.455	45.34	91	12.1223	90.681	1.75	62.14	150	14.582	109.08
1.460	45.68	92	12.1640	90.993	1.76	62.61	152	14.665	109.71
1.465	46.02	93	12.2057	91.305	1.77	63.08	154	14.749	110.32
1.470	46.36	94	12.2473	91.616	1.78	63.54	156	14.832	110.95
1.475	46.69	95	12.2890	91.928	1.79	63.99	158	14.916	111.58
1.480	47.03	96	12.3307	92.240					
1.485	47.36	97	12.3724	92.552	1.80	64.44	160	14.999	112.20
1.490	47.68	98	12.4141	92.864	1.81	64.89	162	15.082	112.82
					1.82	65.33	164	15.166	113.45
1.495	48.01	99	12.4558	93.176	1.83	65.77	166	15.249	114.07
1.500	48.33	100	12.4975	93.488	1.84	66.20	168	15.333	114.70
1.51	48.97	102	12.581	94.11	1.85	66.62	170	15.416	115.31
1.52	49.61	104	12.644	94.79	1.86	67.04	172	15.499	115.94
1.53	50.23	106	12.748	95.36	1.87	67.46	174	15.583	116.56
1.54	50.84	108	12.831	95.98	1.88	67.87	176	15.666	117.19
1.55	51.45	110	12.914	96.61	1.89	68.28	178	15.750	117.81
1.56	52.05	112	12.998	97.23					
1.57	52.64	114	13.081	97.85	1.90	68.68	180	15.832	118.43
1.58	53.23	116	13.165	98.48	1.91	69.08	182	15.916	119.06
1.59	53.81	118	13.248	99.10	1.92	69.48	184	16.000	119.68
					1.93	69.87	186	16.083	120.31
1.60	54.38	120	13.331	99.73	1.94	70.26	188	16.166	120.93
1.61	54.94	122	13.415	100.35	1.95	70.64	190	16.250	121.56
1.62	55.49	124	13.498	100.97	1.96	71.02	192	16.333	122.18
1.63	56.04	126	13.582	101.60	1.97	71.40	194	16.417	122.80
1.64	56.59	128	13.665	102.22	1.98	71.77	196	16.500	123.43
1.65	57.12	130	13.748	102.84	1.99	72.14	198	16.583	124.05
1.66	57.65	132	13.832	103.47	2.00	72.50	200	16.667	124.68

[a] Baumé scale.
[b] Twaddell scale.

6 STANDARD SIZES

6.1 Preferred Numbers

Selection of standard sizes or ratings of many diverse products can be performed advantageously through the use of a geometrically based progression introduced by C. Renard. He originally adopted as a basis a rule that would yield a 10th multiple of the value a after every 5th step of the series:

$$a \times q^5 = 10a \quad or \quad q = \sqrt[5]{10}$$

where the numerical series $a, a[\sqrt[5]{10}], a[\sqrt[5]{10}]^2, a[\sqrt[5]{10}]^3, a[\sqrt[5]{10}]^4$, $10a$, the values of which, to five significant figures, are a, $1.5849a$, $2.5119a$, $3.9811a$, $6.309a$, $10a$.

Renard's idea was to substitute, for these values, more rounded but more practical values. He adopted as a a power of 10, positive, nil, or negative, obtaining the series 10, 16, 25, 40, 63, 100, which may be continued in both directions.

From this series, designated by the symbol R5, the R10, R20, R40 series were formed, each adopted ratio being the square root of the preceding one: $\sqrt[10]{10}$, $\sqrt[20]{10}$, $\sqrt[40]{10}$. Thus each series provided Renard with twice as many steps in a decade as the preceding one.

Preferred numbers are immediately applicable to commercial sizes and ratings of products. It is advantageous to minimize the number of initial sizes and also to have adequate provision for logical expansion if and when additional sizes are required. By making the initial sizes correspond to a coarse series such as R5, unnecessary expense can be avoided if subsequent demand for the product is disappointing. If, on the other hand, the product is accepted, intermediate sizes may be selected in a rational manner by using the next finer series R10, and so on. Such a procedure assures a justifiable relationship between successive sizes and is a decided contrast to haphazard selection.

The application of preferred numbers to raw material sizes and to the dimensions of parts also has enormously important potentialities. Under present conditions, commercial sizes of material are the result of a great many dissimilar gauge systems. The current trend in internationally acceptable metric sizing is to use preferred numbers. Even here, though, in the midst of the greatest opportunity for worldwide standardization through the acceptance of Renard series, we have fallen prey to our individualistic nature. The preferred number 1.6 is used by most nations as a standard 1.6 mm material thickness. German manufacturers, however, like 1.5 mm of the International Organization for Standardization (ISO) 497 for a more rounded preferred number. Similarly in metric screw sizes, 6.3 mm is consistent with the preferred number series; yet, 6.0 mm (more rounded) has been adopted as a standard fastener diameter.

The International Electrochemical Commission (IEC) used preferred numbers to establish standard current ratings in amperes as follows: 1, 1.25, 1.6, 2.5, 3.15, 4.5, 6.3. Notice that R10 series is used except for 4.5, which is a third step R20 series.

The American Wire Gauge size for copper wire is based on a geometric series. However, instead of using 1.1220, the rounded value of $\sqrt[20]{10}$, in $a \times q^{20} = 10a$, the q chosen is 1.123.

A special series of preferred numbers is used for designating the characteristic values of capacitors, resistors, inductors, and other electronic products. Instead of using the Renard series R5, R10, R20, R40, R80 as derived from the geometric series of numbers $10^{N/5}$, $10^{N/10}$, $10^{N/20}$, $10^{N/40}$, $10^{N/80}$, the geometric series used is $10^{N/6}$, $10^{N/12}$, $10^{N/24}$, $10^{N/48}$, $10^{N/96}$, $10^{N/192}$, which are designated respectively E6, E12, E24, E48, E96, E192.

It should be evident that any series of preferred numbers can be generated to serve any specific case. Examples taken from the American National Standards Institute (ANSI) and ISO standards are reproduced in Tables 65–68.

Table 65 Basic Series of Preferred Numbers: R5, R10, R20, and R40 Series

				Theoretical Values		
R5	R10	R20	R40	Mantissas of Logarithms	Calculated Values	Differences between Basic Series and Calculated Values (%)
1.00	1.00	1.00	1.00	000	1.0000	0
			1.06	025	1.0593	+0.07
		1.12	1.12	050	1.1220	−0.18
			1.18	075	1.1885	−0.71
	1.25	1.25	1.25	100	1.2589	−0.71
			1.32	125	1.3335	−1.01
		1.40	1.40	150	1.4125	−0.88
			1.50	175	1.4962	+0.25
1.60	1.60	1.60	1.60	200	1.5849	+0.95
			1.70	225	1.6788	+1.26
		1.80	1.80	250	1.7783	+1.22
			1.90	275	1.8836	+0.87
	2.00	2.00	2.00	300	1.9953	+0.24
			2.12	325	2.1135	+0.31
		2.24	2.24	350	2.2387	+0.06
			2.36	375	2.3714	−0.48
2.50	2.50	2.50	2.50	400	2.5119	−0.47
			2.65	425	2.6607	−0.40
		2.80	2.80	450	2.8184	−0.65
			3.00	475	2.9854	+0.49
	3.15	3.15	3.15	500	3.1623	−0.39
			3.35	525	3.3497	+0.01
		3.55	3.55	550	3.5481	+0.05
			3.75	575	3.7584	−0.22

Table 65 (*Continued*)

R5	R10	R20	R40	Theoretical Values: Mantissas of Logarithms	Theoretical Values: Calculated Values	Differences between Basic Series and Calculated Values (%)
4.00	4.00	4.00	4.00	600	3.9811	+0.47
			4.25	625	4.2170	+0.78
		4.50	4.50	650	4.4668	+0.74
			4.75	675	4.7315	+0.39
	5.00	5.00	5.00	700	5.0119	−0.24
			5.30	725	5.3088	−0.17
		5.60	5.60	750	5.6234	−0.42
			6.00	775	5.9566	+0.73
6.30	6.30	6.30	6.30	800	6.3096	−0.15
			6.70	825	6.6834	+0.25
		7.10	7.10	850	7.0795	+0.29
			7.50	875	7.4989	+0.01
	8.00	8.00	8.00	900	7.9433	+0.71
			8.50	925	8.4140	+1.02
		9.00	9.00	950	8.9125	+0.98
			9.50	975	9.4406	+0.63
10.00	10.00	10.00	10.00	000	10.0000	0

Table 66 Basic Series of Preferred Numbers: R80 Series

1.00	1.80	3.15	5.60
1.03	1.85	3.25	5.80
1.06	1.90	3.35	6.00
1.09	1.95	3.45	6.15
1.12	2.00	3.55	6.30
1.15	2.06	3.65	6.50
1.18	2.12	3.75	6.70
1.22	2.18	3.87	6.90
1.25	2.24	4.00	7.10
1.28	2.30	4.12	7.30
1.32	2.36	4.25	7.50
1.36	2.43	4.37	7.75
1.40	2.50	4.50	8.00
1.45	2.58	4.62	8.25
1.50	2.65	4.75	8.50
1.55	2.72	4.87	8.75
1.60	2.80	5.00	9.00
1.65	2.90	5.15	9.25
1.70	3.00	5.20	9.50
1.75	3.07	5.45	9.75

Table 67 Expansion of R5 Series

Preferred Number	Divided by 10	Multiplied by 10	Multiplied by 100	Multiplied by 1000
1.0	0.10	10	100	1000
1.6	0.16	16	160	1600
2.5	0.25	25	250	2500
4.0	0.40	40	400	4000
6.3	0.63	63	630	6300

Table 68 Rounding of Preferred Numbers[a]

Preferred Number	First Rounding	Second Rounding
1.12	1.1	1.1
1.25	1.25	1.2
1.60	1.6	1.5[a]
2.24	2.2	2.2
3.15	3.2	3.0
3.55	3.6	3.5
5.60	5.6	5.5
6.30	6.3	6.0
7.10	7.1	7.0

[a] Rounded only when using the R5 or R10 series.

Applicable Documents Adoption of Renard's preferred number system by international standardization bodies resulted in a host of national standards being generated for particular applications. The current organization in the United States that is charged with generating American national standards is the ANSI. Accordingly, the following national and international standards are in use in the United States.

ANSI Z17.1-1973	American National Standard for Preferred Numbers
ANSI C83.2-1971	American National Standard Preferred Values for Components for Electronic Equipment
EIA Standard RS-385	Preferred Values for Components for Electronic Equipment (issued by the Electronics Industries Association; Same as ANSI C83.2-1971)
ISO 3-1973	Preferred numbers—series of preferred numbers
ISO 17-1973	Guide to the use of preferred numbers and of series of preferred numbers
ISO 497-1973	Guide to the choice of series of preferred numbers and of series containing more rounded values of preferred numbers

Table 67 shows the expansibility of preferred numbers in the positive direction. The same expansibility can be made in the negative direction. Table 68 shows a deviation by roundings for cases where adhering to a basic preferred number would be absurd as in 31.5 teeth in a gear when clearly 32 makes sense.

6.2 Gages

Table 69 U.S. Standard Gage[a] for Sheet and Plate Iron and Steel and Its Extension[b]

Gage Number	Weight per Square Foot		Weight per Square Meter	Approximate Thickness: Wrought Iron, 480 lb/ft^3		Approximate Thickness: Steel and open-hearth Iron, 489.6 lb/ft^3	
	oz.	lb	kg	in.	mm	in.	mm
0000000	320	20.00	97.65	0.500	12.70	0.490	12.45
000000	300	18.75	91.55	0.469	11.91	0.460	11.67
00000	280	17.50	85.44	0.438	11.11	0.429	10.90
0000	260	16.25	79.34	0.406	10.32	0.398	10.12
000	240	15.00	73.24	0.375	9.52	0.368	9.34
00	220	13.75	67.13	0.344	8.73	0.337	8.56
0	200	12.50	61.03	0.312	7.94	0.306	7.78
1	180	11.25	54.93	0.2812	7.14	0.2757	7.00
2	170	10.62	51.88	0.2656	6.75	0.2604	6.62
3	160	10.00	48.82	0.2500	6.35	0.2451	6.23
4	150	9.375	45.77	0.2344	5.95	0.2298	5.84
5	140	8.750	42.72	0.2188	5.56	0.2145	5.45
6	130	8.125	39.67	0.2031	5.16	0.1991	5.06
7	120	7.500	36.62	0.1875	4.76	0.1838	4.67
8	110	6.875	33.57	0.1719	4.37	0.1685	4.28
9	100	6.250	30.52	0.1562	3.97	0.1532	3.89
10	90	5.625	27.46	0.1406	3.57	0.1379	3.50
11	80	5.000	24.41	0.1250	3.18	0.1225	3.11
12	70	4.375	21.36	0.1094	2.778	0.1072	2.724
13	60	3.750	18.31	0.0938	2.381	0.0919	2.335
14	50	3.125	15.26	0.0781	1.984	0.0766	1.946
15	45	2.812	13.73	0.0703	1.786	0.0689	1.751
16	40	2.500	12.21	0.0625	1.588	0.0613	1.557
17	36	2.250	10.99	0.0562	1.429	0.0551	1.400
18	32	2.000	9.765	0.0500	1.270	0.0490	1.245
19	28	1.750	8.544	0.0438	1.111	0.0429	1.090
20	24	1.500	7.324	0.0375	0.952	0.0368	0.934
21	22	1.375	6.713	0.0344	0.873	0.0337	0.856
22	20	1.250	6.103	0.0312	0.794	0.0306	0.778
23	18	1.125	5.493	0.0281	0.714	0.0276	0.700
24	16	1.000	4.882	0.0250	0.635	0.0245	0.623
25	14	0.8750	4.272	0.0219	0.556	0.0214	0.545
26	12	0.7500	3.662	0.0188	0.476	0.0184	0.467

Table 69 (*Continued*)

Gage Number	Weight per Square Foot		Weight per Square Meter	Approximate Thickness			
				Wrought Iron, 480 lb/ft^3		Steel and open-hearth Iron, 489.6 lb/ft^3	
	oz.	lb	kg	in.	mm	in.	mm
27	11	0.6875	3.357	0.0172	0.437	0.0169	0.428
28	10	0.6250	3.052	0.0156	0.397	0.0153	0.389
29	9	0.5625	2.746	0.0141	0.357	0.0138	0.350
30	8	0.5000	2.441	0.0125	0.318	0.0123	0.311
31	7	0.4375	2.136	0.0109	0.278	0.0107	0.272
32	$6\frac{1}{2}$	0.4062	1.983	0.0102	0.258	0.0100	0.253
33	6	0.3750	1.831	0.0094	0.238	0.0092	0.233
34	$5\frac{1}{2}$	0.3438	1.678	0.0086	0.218	0.0084	0.214
35	5	0.3125	1.526	0.0078	0.198	0.0077	0.195
36	$4\frac{1}{2}$	0.2812	1.373	0.0070	0.179	0.0069	0.175
37	$4\frac{1}{4}$	0.2656	1.297	0.0066	0.169	0.0065	0.165
38	4	0.2500	1.221	0.0062	0.159	0.0061	0.156
39	$3\frac{3}{4}$	0.2344	1.144	0.0059	0.149	0.0057	0.146
40	$3\frac{1}{2}$	0.2188	1.068	0.0055	0.139	0.0054	0.136
41	$3\frac{3}{8}$	0.2109	1.030	0.0053	0.134	0.0052	0.131
42	$3\frac{1}{4}$	0.2031	0.9917	0.0051	0.129	0.0050	0.126
43	$3\frac{1}{8}$	0.1953	0.9536	0.0049	0.124	0.0048	0.122
44	3	0.1875	0.9155	0.0047	0.119	0.0046	0.117

[a] For the Galvanized Sheet Gage, add 2.5 oz to the weight per square foot as given in the table. Gage numbers below 8 and above 34 are not used in the Galvanized Sheet Gage. [b] Gage numbers greater than 38 were not in the standard as set up by law but are in general use.

Table 70 American Wire Gage: Weights of Copper, Aluminum, and Brass Sheets and Plates

Gage Number	Thickness		Approximate Weight,[a] lb/ft^2		
	in.	mm	Copper	Aluminum	Commercial (High) Brass
0000	0.4600	11.68	21.27	6.49	20.27
000	0.4096	10.40	18.94	5.78	18.05
00	0.3648	9.266	16.87	5.14	16.07
0	0.3249	8.252	15.03	4.58	14.32
1	0.2893	7.348	13.38	4.08	12.75
2	0.2576	6.544	11.91	3.632	11.35
3	0.2294	5.827	10.61	3.234	10.11
4	0.2043	5.189	9.45	2.880	9.00
5	0.1819	4.621	8.41	2.565	8.01
6	0.1620	4.115	7.49	2.284	7.14
7	0.1443	3.665	6.67	2.034	6.36
8	0.1285	3.264	5.94	1.812	5.66
9	0.1144	2.906	5.29	1.613	5.04
10	0.1019	2.588	4.713	1.437	4.490
11	0.0907	2.305	4.195	1.279	3.996
12	0.0808	2.053	3.737	1.139	3.560
13	0.0720	1.828	3.330	1.015	3.172
14	0.0641	1.628	2.965	0.904	2.824
15	0.0571	1.450	2.641	0.805	2.516

(*Continues*)

Table 70 (*Continued*)

	Thickness		Approximate Weight,[a] lb/ft^2		
Gage Number	in.	mm	Copper	Aluminum	Commercial (High) Brass
16	0.0508	1.291	2.349	0.716	2.238
17	0.0453	1.150	2.095	0.639	1.996
18	0.0403	1.024	1.864	0.568	1.776
19	0.0359	0.9116	1.660	0.506	1.582
20	0.0320	0.8118	1.480	0.451	1.410
21	0.0285	0.7230	1.318	0.402	1.256
22	0.0253	0.6438	1.170	0.3567	1.115
23	0.0226	0.5733	1.045	0.3186	0.996
24	0.0201	0.5106	0.930	0.2834	0.886
25	0.0179	0.4547	0.828	0.2524	0.789
26	0.0159	0.4049	0.735	0.2242	0.701
27	0.0142	0.3606	0.657	0.2002	0.626
28	0.0126	0.3211	0.583	0.1776	0.555
29	0.0113	0.2859	0.523	0.1593	0.498
30	0.0100	0.2546	0.4625	0.1410	0.4406
31	0.00893	0.2268	0.4130	0.1259	0.3935
32	0.00795	0.2019	0.3677	0.1121	0.3503
33	0.00708	0.1798	0.3274	0.0998	0.3119
34	0.00630	0.1601	0.2914	0.0888	0.2776
35	0.00561	0.1426	0.2595	0.0791	0.2472
36	0.00500	0.1270	0.2312	0.0705	0.2203
37	0.00445	0.1131	0.2058	0.0627	0.1961
38	0.00397	0.1007	0.1836	0.0560	0.1749
39	0.00353	0.0897	0.1633	0.0498	0.1555
40	0.00314	0.0799	0.1452	0.0443	0.1383

[a] Assumed specific gravities or densities in grams per cubic centimeter; copper, 8.89; aluminum, 2.71; brass, 8.47.

Wire Gages The sizes of wires having a diameter less than $\frac{1}{2}$ in. are usually stated in terms of certain arbitrary scales called "gages." The size or gage number of a solid wire refers to the cross section of the wire perpendicular to its length; the size or gage number of a stranded wire refers to the total cross section of the constituent wires, irrespective of the pitch of the spiraling. Larger wires are usually described in terms of their area expressed in circular mils. A circular mil is the area of a circle 1 mil in diameter, and the area of any circle in circular mils is equal to the square of its diameter in mils.

Table 71 Comparison of Wire Gage Diameters in Mils[a]

Gage No.	American Wire Gage (Brown & Sharpe)	Steel Wire Gage	Birmingham Wire Gage (Stubs')	Old English Wire Gage (London)	Stubs' Steel Wire Gage	(British) Standard Wire Gage	Metric Gage[b]
7–0	—	490.0	—	—	—	500	—
6–0	—	461.5	—	—	—	464	—
5–0	—	430.5	—	—	—	432	—
4–0	460	393.8	454	454	—	400	—
3–0	410	362.5	425	425	—	372	—
2–0	365	331.0	380	380	—	348	—
0	325	306.5	340	340	—	324	—
1	289	283.0	300	300	227	300	3.94

Table 71 (*Continued*)

Gage No.	American Wire Gage (B. & S.)	Steel Wire Gage	Birmingham Wire Gage (Stubs')	Old English Wire Gage (London)	Stubs' Steel Wire Gage	(British) Standard Wire Gage	Metric Gage[b]
2	258	262.5	284	284	219	276	7.87
3	229	243.7	259	259	212	252	11.8
4	204	225.3	238	238	207	232	15.7
5	182	207.0	220	220	204	212	19.7
6	162	192.0	203	203	201	192	23.6
7	144	177.0	180	180	199	176	27.6
8	128	162.0	165	165	197	160	31.5
9	114	148.3	148	148	194	144	35.4
10	102	135.0	134	134	191	128	39.4
11	91	120.5	120	120	188	116	—
12	81	105.5	109	109	185	104	47.2
13	72	91.5	95	95	182	92	—
14	64	80.0	83	83	180	80	55.1
15	57	72.0	72	72	178	72	—
16	51	62.5	65	65	175	64	63.0
17	45	54.0	58	58	172	56	—
18	40	47.5	49	49	168	48	70.9
19	36	41.0	42	42	164	40	—
20	32	34.8	35	35	161	36	78.7
21	28.5	31.7	32	31.5	157	32	—
22	25.3	28.6	28	29.5	155	28	—
23	22.6	25.8	25	27.0	153	24	—
24	20.1	23.0	22	25.0	151	22	—
25	17.9	20.4	20	23.0	148	20	98.4
26	15.9	18.1	18	20.5	146	18	—
27	14.2	17.3	16	18.75	143	16.4	—
28	12.6	16.2	14	16.50	139	14.8	—
29	11.3	15.0	13	15.50	134	13.6	—
30	10.0	14.0	12	13.75	127	12.4	118
31	8.9	13.2	10	12.25	120	11.6	—
32	8.0	12.8	9	11.25	115	10.8	—
33	7.1	11.8	8	10.25	112	10.0	—
34	6.3	10.4	7	9.50	110	9.2	—
35	5.6	9.5	5	9.00	108	8.4	138
36	5.0	9.0	4	7.50	106	7.6	—
37	4.5	8.5	—	6.50	103	6.8	—
38	4.0	8.0	—	5.75	101	6.0	—
39	3.5	7.5	—	5.00	99	5.2	—
40	3.1	7.0	—	4.50	97	4.8	157
41	—	6.6	—	—	95	4.4	—
42	—	6.2	—	—	92	4.0	—
43	—	6.0	—	—	88	3.6	—
44	—	5.8	—	—	85	3.2	—
45	—	5.5	—	—	81	2.8	177
46	—	5.2	—	—	79	2.4	—
47	—	5.0	—	—	77	2.0	—
48	—	4.8	—	—	75	1.6	—
49	—	4.6	—	—	72	1.2	—
50	—	4.4	—	—	69	1.0	197

[a] Bureau of Standards, Circulars No. 31 and No. 67.
[b] For diameters corresponding to metric gage numbers, 1.2, 1.4, 1.6, 1.8, 2.5, 3.5, and 4.5, divide those of 12, 14, etc., by 10.

6.3 Paper Sizes

Table 72 Standard Engineering Drawing Sizes[a]

Flat Sizes[b]

Size Designation	Width[c] (Vertical)	Length (Horizontal)	Margin Horizontal	Margin Vertical
A (horizontal)	8.5	11.0	0.38	0.25
A (vertical)	11.0	8.5	0.25	0.38
B	11.0	17.0	0.38	0.62
C	17.0	22.0	0.75	0.50
D	22.0	34.0	0.50	1.00
E	34.0	44.0	1.00	0.50
F	28.0	40.0	0.50	0.50

Roll Sizes

Size Designation	Width[b] (Vertical)	Length[c] (Horizontal) Min	Length[c] (Horizontal) Max	Margin[c] Horizontal	Margin[c] Vertical
G	11.0	22.5	90.0	0.38	0.50
H	28.0	44.0	143.0	0.50	0.50
J	34.0	55.0	176.0	0.50	0.50
K	40.0	55.0	143.0	0.50	0.50

[a] See ANSI Y14.1-1980.
[b] All dimensions are in inches.
[c] Not including added protective margins.

International Paper Sizes Countries that are committed to the International System of Units (SI) have a standard series of paper sizes for printing, writing, and drafting. These paper sizes are called the "international paper sizes."

The advantages of the international paper sizes are as follows:

1. The ratio of width to length remains constant for every size, namely:

$$\frac{\text{Width}}{\text{Length}} = \frac{1}{\sqrt{2}} \qquad \text{or} \qquad \frac{1}{1.414} \text{ approximately}$$

Since this is the same ratio as the D aperture in the unitized 35-mm microfilm frame, the advantages are apparent.

2. If a sheet is cut in half, that is, if the $\sqrt{2}$ length is cut in half, the two halves retain the constant width-to-length ratio of $1/\sqrt{2}$. No other ratio could do this.

3. All international sizes are created from the A-0 size by single cuts without waste. In storing or stacking they fit together like parts of a jigsaw puzzle—without waste.

Table 73 Eleven International Paper Sizes

International Paper Size	Millimeters	Inches, Approximate
A-0	841 × 1189	$33\frac{1}{8} \times 46\frac{3}{4}$
A-1	594 × 841	$23\frac{3}{8} \times 33\frac{1}{8}$
A-2	420 × 594	$16\frac{1}{2} \times 23\frac{3}{8}$
A-3	297 × 420	$11\frac{3}{4} \times 16\frac{1}{2}$
A-4	210 × 297	$8\frac{1}{4} \times 11\frac{3}{4}$
A-5	148 × 210	$5\frac{7}{8} \times 8\frac{1}{4}$
A-6	105 × 148	$4\frac{1}{8} \times 5\frac{7}{8}$
A-7	74 × 105	$2\frac{7}{8} \times 4\frac{1}{8}$
A-8	52 × 74	$2 \times 2\frac{7}{8}$
A-9	37 × 52	$1\frac{1}{2} \times 2$
A-10	26 × 37	$1 \times 1\frac{1}{2}$

6.4 Sieve Sizes

Table 74 Tyler Standard Screen Scale Sieves

This screen scale has as its base an opening of 0.0029 in., which is the opening in 200-mesh 0.0021-in. wire, the standard sieve, as adopted by the Bureau of Standards of the U.S. government, the openings increasing in the ratio of the square root of 2 or 1.414.

Where a closer sizing is required, column 5 shows the Tyler Standard Screen Scale with intermediate sieves. In this series the sieve openings increase in the ratio of the fourth root of 2, or 1.189.

Tyler Standard Screen Scale $\sqrt{2}$ or 1.414 Openings (in.) (1)	Every Other Sieve from 0.0029 to 0.742 in., Ratio of 2 to 1 (2)	Every Other Sieve from 0.0041 to 1.050 in., Ratio of 2 to 1 (3)	Every Fourth Sieve from 0.0029 to 0.742 in., Ratio of 4 to 1 (4)	For Closer Sizing Sieves from 0.0029 to 1.050 in., Ratio $\sqrt[4]{2}$ or 1.189 (5)	openings (mm) (6)	Openings in Fractions of inch (approx.) (7)	Mesh (8)	Diameter of Wire (9)
1.050	—	1.050	—	1.050	26.67	1	—	0.148
—	—	—	—	0.883	22.43	$\frac{7}{8}$	—	0.135
0.742	0.742	—	0.742	0.742	18.85	$\frac{3}{4}$	—	0.135
—	—	—	—	0.624	15.85	$\frac{5}{8}$	—	0.120
0.525	—	0.525	—	0.525	13.33	$\frac{1}{2}$	—	0.105
—	—	—	—	0.441	11.20	$\frac{7}{16}$	—	0.105
0.371	0.371	—	—	0.371	9.423	$\frac{3}{8}$	—	0.092
—	—	—	—	0.312	7.925	$\frac{5}{16}$	$2\frac{1}{2}$	0.088
0.263	—	0.263	—	0.263	6.680	$\frac{1}{4}$	3	0.070
—	—	—	—	0.221	5.613	$\frac{7}{32}$	$3\frac{1}{2}$	0.065
0.185	0.185	—	0.185	0.185	4.699	$\frac{3}{16}$	4	0.065
—	—	—	—	0.156	3.962	$\frac{5}{32}$	5	0.044
0.131	—	0.131	—	0.131	3.327	$\frac{1}{8}$	6	0.036
—	—	—	—	0.110	2.794	$\frac{7}{64}$	7	0.0328
0.093	0.093	—	—	0.093	2.362	$\frac{3}{32}$	8	0.032
—	—	—	—	0.078	1.981	$\frac{5}{84}$	9	0.033
0.065	—	0.065	—	0.065	1.651	$\frac{1}{16}$	10	0.035
—	—	—	—	0.055	1.397	—	12	0.028
0.046	0.046	—	0.046	0.046	1.168	$\frac{3}{64}$	14	0.025
—	—	—	—	0.0390	0.991	—	16	0.0235
0.0328	—	0.0328	—	0.0328	0.833	$\frac{1}{32}$	20	0.0172
—	—	—	—	0.0276	0.701	—	24	0.0141
0.0232	0.0232	—	—	0.0232	0.589	—	28	0.0125
—	—	—	—	0.0195	0.495	—	32	0.0118
0.0164	—	0.0164	—	0.0164	0.417	$\frac{1}{64}$	35	0.0122
—	—	—	—	0.0138	0.351	—	42	0.0100
0.0116	0.0116	—	0.0116	0.0116	0.295	—	48	0.0092
—	—	—	—	0.0097	0.246	—	60	0.0070
0.0082	—	0.0082	—	0.0082	0.208	—	65	0.0072
—	—	—	—	0.0069	0.175	—	80	0.0056
0.0058	0.0058	—	—	0.0058	0.147	—	100	0.0042
—	—	—	—	0.0049	0.124	—	115	0.0038
0.0041	—	0.0041	—	0.0041	0.104	—	150	0.0026
—	—	—	—	0.0035	0.088	—	170	0.0024
0.0029	0.0029	—	0.0029	0.0029	0.074	—	200	0.0021

Table 75 Nominal Dimensions, Permissible Variations, and Limits for Woven Wire Cloth of Standard Sieves, U.S. Series, ASTM Standard[a]

Size or Sieve Designation		Sieve Opening		Permissible Variations in Average Opening	Permissible Variations in Maximum Opening	Wire Diameter	
μm	No.	mm	in. (approx. equivalents)	(±%)	(±%)	mm	in. (approx. equivalents)
5660	$3\frac{1}{2}$	5.66	0.233	3	10	1.28–1.90	0.050–0.075
4760	4	4.76	0.187	3	10	1.14–1.68	0.045–0.066
4000	5	4.00	0.157	3	10	1.00–1.47	0.039–0.058
3360	6	3.36	0.132	3	10	0.87–1.32	0.034–0.052
2830	7	2.83	0.111	3	10	0.80–1.20	0.031–0.047
2380	8	2.38	0.0937	3	10	0.74–1.10	0.0291–0.0433
2000	10	2.00	0.0787	3	10	0.68–1.00	0.0268–0.0394
1680	12	1.68	0.0661	3	10	0.62–0.90	0.0244–0.0354
1410	14	1.41	0.0555	3	10	0.56–0.80	0.0220–0.0315
1190	16	1.19	0.0469	3	10	0.50–0.70	0.0197–0.0276
1000	18	1.00	0.0394	5	15	0.43–0.62	0.0169–0.0244
840	20	0.84	0.0331	5	15	0.38–0.55	0.0150–0.0217
710	25	0.71	0.0280	5	15	0.33–0.48	0.0130–0.0189
590	30	0.59	0.0232	5	15	0.29–0.42	0.0114–0.0165
500	35	0.50	0.0197	5	15	0.26–0.37	0.0102–0.0146
420	40	0.42	0.0165	5	25	0.23–0.33	0.0091–0.0130
350	45	0.35	0.0138	5	25	0.20–0.29	0.0079–0.0114
297	50	0.297	0.0117	5	25	0.170–0.253	0.0067–0.0100
250	60	0.250	0.0098	5	25	0.149–0.220	0.0059–0.0087
210	70	0.210	0.0083	5	25	0.130–0.187	0.0051–0.0074
177	80	0.177	0.0070	6	40	0.114–0.154	0.0045–0.0061
149	100	0.149	0.0059	6	40	0.096–0.125	0.0038–0.0049
125	120	0.125	0.0049	6	40	0.079–0.103	0.0031–0.0041
105	140	0.105	0.0041	6	40	0.063–0.087	0.0025–0.0034
88	170	0.088	0.0035	6	40	0.054–0.073	0.0021–0.0029
74	200	0.074	0.0029	7	60	0.045–0.061	0.0018–0.0024
62	230	0.062	0.0024	7	90	0.039–0.052	0.0015–0.0020
53	270	0.053	0.0021	7	90	0.035–0.046	0.0014–0.0018
44	325	0.044	0.0017	7	90	0.031–0.040	0.0012–0.0016
37	400	0.037	0.0015	7	90	0.023–0.035	0.0009–0.0014

[a] For sieves from the 1000-μm (No. 18) to the 37-μm (No. 400) size, inclusive, not more than 5% of the openings shall exceed the nominal opening by more than one-half of the permissible variation in the maximum opening.

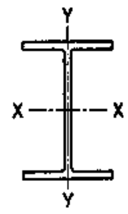
6.5 Standard Structural Sizes — Steel

Steel Sections. Tables 76–83 give the dimensions, weights, and properties of *rolled steel* structural sections, including wide-flange sections, American standard beams, channels, angles, tees, and zees. The values for the various structural forms, taken from the eighth edition, 1980, of *Steel Construction*, by the kind permission of the publisher, the American Institute of Steel Construction, give the section specifications required in designing steel structures. The theory of design is covered in Section 4—Mechanics of Deformable Bodies.

Most of the sections can be supplied promptly steel mills. Owing to variations in the rolling practice of the different mills, their products are not identical, although their divergence from the values given in the tables is practically negligible. For standardization, only the lesser values are given, and therefore they are on the side of safety.

Further information on sections listed in the tables, together with information on other products and on the requirements for placing orders, may be gathered from mill catalogs.

Table 76 Properties of Wide-Flange Sections



Nominal Size (in.)	Weight per Foot (lb)	Area (in.^{2})	Depth (in.)	Flange Width (in.)	Flange Thickness (in.)	Web Thickness (in.)	Axis X–X I (in.^{4})	Axis X–X S (in.^{3})	Axis X–X r (in.)	Axis Y–Y I (in.^{4})	Axis Y–Y S (in.^{3})	Axis Y–Y r (in.)
$36 \times 16\frac{1}{2}$	300	88.17	36.72	16.655	1.680	0.945	20290.2	1105.1	15.17	1225.2	147.1	3.73
	280	82.32	36.50	16.595	1.570	0.885	18819.3	1031.2	15.12	1127.5	135.9	3.70
	260	76.56	36.24	16.555	1.440	0.845	17233.8	951.1	15.00	1020.6	123.3	3.65
	245	72.03	36.06	16.512	1.350	0.802	16092.2	892.5	14.95	944.7	114.4	3.62
	230	67.73	35.88	16.475	1.260	0.765	14988.4	835.5	14.88	870.9	105.7	3.59
36×12	194	57.11	36.48	12.117	1.260	0.770	12103.4	663.6	14.56	355.4	58.7	2.49
	182	53.54	36.32	12.072	1.180	0.725	11281.5	621.2	14.52	327.7	54.3	2.47
	170	49.98	36.16	12.027	1.100	0.680	10470.0	579.1	14.47	300.6	50.0	2.45
	160	47.09	36.00	12.000	1.020	0.653	9738.8	541.0	14.38	275.4	45.9	2.42
	150	44.16	35.84	11.972	0.940	0.625	9012.1	502.9	14.29	250.4	41.8	2.38
$33 \times 15\frac{3}{4}$	240	70.52	33.50	15.865	1.400	0.830	13585.1	811.1	13.88	874.3	110.2	3.52
	220	64.73	33.25	15.810	1.275	0.775	12312.1	740.6	13.79	782.4	99.0	3.48
	200	58.79	33.00	15.750	1.150	0.715	11048.2	669.6	13.71	691.7	87.8	3.43
$33 \times 11\frac{1}{2}$	152	44.71	33.50	11.565	1.055	0.635	8147.6	486.4	13.50	256.1	44.3	2.39
	141	41.51	33.31	11.535	0.960	0.605	7442.2	446.8	13.39	229.7	39.8	2.35
	130	38.26	33.10	11.510	0.855	0.580	6699.0	404.8	13.23	201.4	35.0	2.29
30×15	210	61.78	30.38	15.105	1.315	0.775	9872.4	649.9	12.64	707.9	93.7	3.38
	190	55.90	30.12	15.040	1.185	0.710	8825.9	586.1	12.57	624.6	83.1	3.34
	172	50.65	29.88	14.985	1.065	0.655	7891.5	528.2	12.48	550.1	73.4	3.30
$30 \times 10\frac{1}{2}$	132	38.83	30.30	10.551	1.000	0.615	5753.1	379.7	12.17	185.0	35.1	2.18
	124	36.45	30.16	10.521	0.930	0.585	5347.1	354.6	12.11	169.7	32.3	2.16
	116	34.13	30.00	10.500	0.850	0.564	4919.1	327.9	12.00	153.2	29.2	2.12
	108	31.77	29.82	10.484	0.760	0.548	4461.0	299.2	11.85	135.1	25.8	2.06
27×14	177	52.10	27.31	14.090	1.190	0.725	6728.6	492.8	11.36	518.9	73.7	3.16
	160	47.04	27.08	14.023	1.075	0.658	6018.6	444.5	11.31	458.0	65.3	3.12
	145	42.68	26.88	13.965	0.975	0.600	5414.3	402.9	11.26	406.9	58.3	3.09
27×10	114	33.53	27.28	10.070	0.932	0.570	4080.5	299.2	11.03	149.6	29.7	2.11
	102	30.01	27.07	10.018	0.827	0.518	3604.1	266.3	10.96	129.5	25.9	2.08
	94	27.65	26.91	9.990	0.747	0.490	3266.7	242.8	10.87	115.1	23.0	2.04
24×14	160	47.04	24.72	14.091	1.135	0.656	5110.3	413.5	10.42	492.6	69.9	3.23
	145	42.62	24.49	14.043	1.020	0.608	4561.0	372.5	10.34	434.3	61.8	3.19
	130	38.21	24.25	14.000	0.900	0.565	4009.5	330.7	10.24	375.2	53.6	3.13
24×12	120	35.29	24.31	12.088	0.930	0.556	3635.3	299.1	10.15	254.0	42.0	2.68
	110	32.36	24.16	12.042	0.855	0.510	3315.0	274.4	10.12	229.1	38.0	2.66
	100	29.43	24.00	12.000	0.775	0.468	2987.3	248.9	10.08	203.5	33.9	2.63
24×9	94	27.63	24.29	9.061	0.872	0.516	2683.0	220.9	9.85	102.2	22.6	1.92
	84	24.71	24.09	9.015	0.772	0.470	2364.3	196.3	9.78	88.3	19.6	1.89
	76	22.37	23.91	8.985	0.682	0.440	2096.4	175.4	9.68	76.5	17.0	1.85
21×13	142	41.76	21.46	13.132	1.095	0.659	3403.1	317.2	9.03	385.9	58.8	3.04
	127	37.34	21.24	13.061	0.985	0.588	3017.2	284.1	8.99	338.6	51.8	3.01
	112	32.93	21.00	13.000	0.865	0.527	2620.6	249.6	8.92	289.7	44.6	2.96
21×9	96	28.21	21.14	9.038	0.935	0.575	2088.9	197.6	8.60	109.3	24.2	1.97
	82	24.10	20.86	8.962	0.795	0.499	1752.4	168.0	8.53	89.6	20.0	1.93

(*Continues*)

Table 76 (*Continued*)

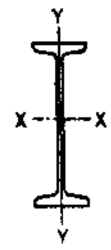
Nominal Size (in.)	Weight per Foot (lb)	Area (in.^{2})	Depth (in.)	Flange Width (in.)	Flange Thickness (in.)	Web Thickness (in.)	Axis X–X I (in.^{4})	Axis X–X S (in.^{3})	Axis X–X r (in.)	Axis Y–Y I (in.^{4})	Axis Y–Y S (in.^{3})	Axis Y–Y r (in.)
$21 \times 8\frac{1}{4}$	73	21.46	21.24	8.295	0.740	0.455	100.3	150.7	8.64	66.2	16.0	1.76
	68	20.02	21.13	8.270	0.685	0.430	1478.3	139.9	8.59	60.4	14.6	1.74
	62	18.23	20.99	8.240	0.615	0.400	1326.8	126.4	8.53	53.1	12.9	1.71
$18 \times 11\frac{3}{4}$	114	33.51	18.48	11.833	0.991	0.595	2033.8	220.1	7.79	255.6	43.2	2.76
	105	30.86	18.32	11.792	0.911	0.554	1852.5	202.2	7.75	231.0	39.2	2.73
	96	28.22	18.16	11.750	0.831	0.512	1674.7	184.4	7.70	206.8	35.2	2.71
$18 \times 8\frac{3}{4}$	85	24.97	18.32	8.838	0.911	0.526	1429.9	156.1	7.57	99.4	22.5	2.00
	77	22.63	18.16	8.787	0.831	0.475	1286.8	141.7	7.54	88.6	20.2	1.98
	70	20.56	18.00	8.750	0.751	0.438	1153.9	128.2	7.49	78.5	17.9	1.95
	64	18.80	17.87	8.715	0.686	0.403	1045.8	117.0	7.46	70.3	16.1	1.93
$18 \times 7\frac{1}{2}$	60	17.64	18.25	7.558	0.695	0.416	984.0	107.8	7.47	47.1	12.5	1.63
	55	16.19	18.12	7.532	0.630	0.390	889.9	98.2	7.41	42.0	11.1	1.61
	50	14.71	18.00	7.500	0.570	0.358	800.6	89.0	7.38	37.2	9.9	1.59
$16 \times 11\frac{1}{2}$	96	28.22	16.32	11.533	0.875	0.535	1355.1	166.1	6.93	207.2	35.9	2.71
	88	25.87	16.16	11.502	0.795	0.504	1222.6	151.3	6.87	185.2	32.2	2.67
$16 \times 8\frac{1}{2}$	78	22.92	16.32	8.586	0.875	0.529	1042.6	127.8	6.74	87.5	20.4	1.95
	71	20.86	16.16	8.543	0.795	0.486	936.9	115.9	6.70	77.9	18.2	1.93
	64	18.80	16.00	8.500	0.715	0.443	833.8	104.2	6.66	68.4	16.1	1.91
	58	17.04	15.86	8.464	0.645	0.407	746.4	94.1	6.62	60.5	14.3	1.88
16×7	50	14.70	16.25	7.073	0.628	0.380	655.4	80.7	6.68	34.8	9.8	1.54
	45	13.24	16.12	7.039	0.563	0.346	583.3	72.4	6.64	30.5	8.7	1.52
	40	11.77	16.00	7.000	0.503	0.307	515.5	64.4	6.62	26.5	7.6	1.50
	36	10.59	15.85	6.992	0.428	0.299	446.3	56.3	6.49	22.1	6.3	1.45
14×16	426	125.25	18.69	16.695	3.033	1.875	6610.3	707.4	7.26	2359.5	282.7	4.34
	398	116.98	18.31	16.590	2.843	1.770	6013.7	656.9	7.17	2169.7	261.6	4.31
	370	108.78	17.94	16.475	2.658	1.655	5454.2	608.1	7.08	1986.0	241.1	4.27
	342	100.59	17.56	16.365	2.468	1.545	4911.5	559.4	6.99	1806.9	220.8	4.24
	314	92.30	17.19	16.235	2.283	1.415	4399.4	511.9	6.90	1631.4	201.0	4.20
	287	84.37	16.81	16.130	2.093	1.310	3912.1	465.5	6.81	1466.5	181.8	4.17
	264	77.63	16.50	16.025	1.938	1.205	3526.0	427.4	6.74	1331.2	166.1	4.14
	246	72.33	16.25	15.945	1.813	1.125	3228.9	397.4	6.68	1226.6	153.9	4.12
	237	69.69	16.12	15.910	1.748	1.090	3080.9	382.2	6.65	1174.8	147.7	4.11
	228	67.06	16.00	15.865	1.688	1.045	2942.4	367.8	6.62	1124.8	141.8	4.10
	219	64.36	15.87	15.825	1.623	1.005	2798.2	352.6	6.59	1073.2	135.6	4.08
	211	62.07	15.75	15.800	1.563	0.980	2671.4	339.2	6.56	1028.6	130.2	4.07
	202	59.39	15.63	15.750	1.503	0.930	2538.8	324.9	6.54	979.7	124.4	4.06
	193	56.73	15.50	15.710	1.438	0.890	2402.4	310.0	6.51	930.1	118.4	4.05
	184	54.07	15.38	15.660	1.378	0.840	2274.8	295.8	6.49	882.7	112.7	4.04
	176	51.73	15.25	15.640	1.313	0.820	2149.6	281.9	6.45	837.9	107.1	4.02
	167	49.09	15.12	15.600	1.248	0.780	2020.8	267.3	6.42	790.2	101.3	4.01
	158	46.47	15.00	15.550	1.188	0.730	1900.6	253.4	6.40	745.0	95.8	4.00
	150	44.08	14.88	15.515	1.128	0.695	1786.9	240.2	6.37	702.5	90.6	3.99
	142	41.85	14.75	15.500	1.063	0.680	1672.2	226.7	6.32	660.1	85.2	3.97
	320[a]	94.12	16.81	16.710	2.093	1.890	4141.7	492.8	6.63	1635.1	195.7	4.17
$14 \times 14\frac{1}{2}$	136	39.98	14.75	14.740	1.063	0.660	1593.0	216.0	6.31	567.7	77.0	3.77
	127	37.33	14.62	14.690	0.998	0.610	1476.7	202.0	6.29	527.6	71.8	3.76
	119	34.99	14.50	14.650	0.938	0.570	1373.1	189.4	6.26	491.8	67.1	3.75
	111	32.65	14.37	14.620	0.873	0.540	1266.5	176.3	6.23	454.9	62.2	3.73
	103	30.26	14.25	14.575	0.813	0.495	1165.8	163.6	6.21	419.7	57.6	3.72
	95	27.94	14.12	14.545	0.748	0.465	1063.5	150.6	6.17	383.7	52.8	3.71
	87	25.56	14.00	14.500	0.688	0.420	966.9	138.1	6.15	349.7	48.2	3.70
14×12	84	24.71	14.18	12.023	0.778	0.451	928.4	130.9	6.13	225.5	37.5	3.02
	78	22.94	14.06	12.000	0.718	0.428	851.2	121.1	6.09	206.9	34.5	3.00
14×10	74	21.76	14.19	10.072	0.783	0.450	796.8	112.3	6.05	133.5	26.5	2.48
	68	20.00	14.06	10.040	0.718	0.418	724.1	103.0	6.02	121.2	24.1	2.46
	61	17.94	13.91	10.000	0.643	0.378	641.5	92.2	5.98	107.3	21.5	2.45

Table 76 (*Continued*)

Nominal Size (in.)	Weight per Foot (lb)	Area (in.^{2})	Depth (in.)	Flange		Web Thickness (in.)	Axis *X–X*			Axis *Y–Y*		
				Width (in.)	Thickness (in.)		*I* (in.^{4})	*S* (in.^{3})	*r* (in.)	*I* (in.^{4})	*S* (in.^{3})	*r* (in.)
14×8	53	15.59	13.94	8.062	0.658	0.370	542.1	77.8	5.90	57.5	14.3	1.92
	48	14.11	13.81	8.031	0.593	0.339	484.9	70.2	5.86	51.3	12.8	1.91
	43	12.65	13.68	8.000	0.528	0.308	429.0	62.7	5.82	45.1	11.3	1.89
$14 \times 6\frac{3}{4}$	38	11.17	14.12	6.776	0.513	0.313	385.3	54.6	5.87	24.6	7.3	1.49
	34	10.00	14.00	6.750	0.453	0.287	339.2	48.5	5.83	21.3	6.3	1.46
	30	8.81	13.86	6.733	0.383	0.270	289.6	41.8	5.73	17.5	5.2	1.41
12×12	190	55.86	14.38	12.670	1.736	1.060	1892.5	263.2	5.82	589.7	93.1	3.25
	161	47.38	13.88	12.515	1.486	0.905	1541.8	222.2	5.70	486.2	77.7	3.20
	133	39.11	13.38	12.365	1.236	0.755	1221.2	182.5	5.59	389.9	63.1	3.16
	120	35.31	13.12	12.320	1.106	0.710	1071.7	163.4	5.51	345.1	56.0	3.13
	106	31.19	12.88	12.230	0.986	0.620	930.7	144.5	5.46	300.9	49.2	3.11
	99	29.09	12.75	12.190	0.921	0.580	858.5	134.7	5.43	278.2	45.7	3.09
	92	27.06	12.62	12.155	0.856	0.545	788.9	125.0	5.40	256.4	42.2	3.08
	85	24.98	12.50	12.105	0.796	0.495	723.3	115.7	5.38	235.5	38.9	3.07
	79	23.22	12.38	12.080	0.736	0.470	663.0	107.1	5.34	216.4	35.8	3.05
	72	21.16	12.25	12.040	0.671	0.430	597.4	97.5	5.31	195.3	32.4	3.04
	65	19.11	12.12	12.000	0.606	0.390	533.4	88.0	5.28	174.6	29.1	3.02
12×10	58	17.06	12.19	10.014	0.641	0.359	476.1	78.1	5.28	107.4	21.4	2.51
	53	15.59	12.06	10.000	0.576	0.345	426.2	70.7	5.23	96.1	19.2	2.48
12×8	50	14.71	12.19	8.077	0.641	0.371	394.5	64.7	5.18	56.4	14.0	1.96
	45	13.24	12.06	8.042	0.576	0.336	350.8	58.2	5.15	50.0	12.4	1.94
	40	11.77	11.94	8.000	0.516	0.294	310.1	51.9	5.13	44.1	11.0	1.94
$12 \times 6\frac{1}{2}$	36	10.59	12.24	6.565	0.540	0.305	280.8	45.9	5.15	23.7	7.2	1.50
	31	9.12	12.09	6.525	0.465	0.265	238.4	39.4	5.11	19.8	6.1	1.47
	27	7.97	11.95	6.500	0.400	0.240	204.1	34.1	5.06	16.6	5.1	1.44
10×10	112	32.92	11.38	10.415	1.248	0.755	718.7	126.3	4.67	235.4	45.2	2.67
	100	29.43	11.12	10.345	1.118	0.685	625.0	112.4	4.61	206.6	39.9	2.65
	89	26.19	10.88	10.275	0.998	0.615	542.4	99.7	4.55	180.6	35.2	2.63
	77	22.67	10.62	10.195	0.868	0.535	457.2	86.1	4.49	153.4	30.1	2.60
	72	21.18	10.50	10.170	0.808	0.510	420.7	80.1	4.46	141.8	27.9	2.59
	66	19.41	10.38	10.117	0.748	0.457	382.5	73.7	4.44	129.2	25.5	2.58
	60	17.66	10.25	10.075	0.683	0.415	343.7	67.1	4.41	116.5	23.1	2.57
	54	15.88	10.12	10.028	0.618	0.368	305.7	60.4	4.39	103.9	20.7	2.56
	49	14.40	10.00	10.000	0.558	0.340	272.9	54.6	4.35	93.0	18.6	2.54
10×8	45	13.24	10.12	8.022	0.618	0.350	248.6	49.1	4.33	53.2	13.3	2.00
	39	11.48	9.94	7.990	0.528	0.318	209.7	42.2	4.27	44.9	11.2	1.98
	33	9.71	9.75	7.964	0.433	0.292	170.9	35.0	4.20	36.5	9.2	1.94
$10 \times 5\frac{3}{4}$	29	8.53	10.22	5.799	0.500	0.289	157.3	30.8	4.29	15.2	5.2	1.34
	25	7.35	10.08	5.762	0.430	0.252	133.2	26.4	4.26	12.7	4.4	1.31
	21	6.19	9.90	5.750	0.340	0.240	106.3	21.5	4.14	9.7	3.4	1.25
8×8	67	19.70	9.00	8.287	0.933	0.575	271.8	60.4	3.71	88.6	21.4	2.12
	58	17.06	8.75	8.222	0.808	0.510	227.3	52.0	3.65	74.9	18.2	2.10
	48	14.11	8.50	8.117	0.683	0.405	183.7	43.2	3.61	60.9	15.0	2.08
	40	11.76	8.25	8.077	0.558	0.365	146.3	35.5	3.53	49.0	12.1	2.04
	35	10.30	8.12	8.027	0.493	0.315	126.5	31.1	3.50	42.5	10.6	2.03
	31	9.12	8.00	8.000	0.433	0.288	109.7	27.4	3.47	37.0	9.2	2.01
$8 \times 6\frac{1}{2}$	28	8.23	8.06	6.540	0.463	0.285	97.8	24.3	3.45	21.6	6.6	1.62
	24	7.06	7.93	6.500	0.398	0.245	82.5	20.8	3.42	18.2	5.6	1.61
$8 \times 5\frac{1}{4}$	20	5.88	8.14	5.268	0.378	0.248	69.2	17.0	3.43	8.5	3.2	1.20
	17	5.00	8.00	5.250	0.308	0.230	56.4	14.1	3.36	6.7	2.6	1.16

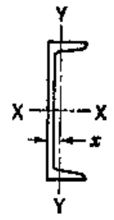
[a] Column core section.

Table 77 Properties of American Standard Beams



Nominal Size (in.)	Weight per Foot (lb)	Area (in.^{2})	Depth (in.)	Flange Width (in.)	Flange Thickness (in.)	Web Thickness (in.)	Axis $X-X$ I (in.^{4})	Axis $X-X$ S (in.^{3})	Axis $X-X$ r (in.)	Axis $Y-Y$ I (in.^{4})	Axis $Y-Y$ S (in.^{3})	Axis $Y-Y$ r (in.)
$24 \times 7\frac{7}{8}$	120.0	35.13	24.00	8.048	1.102	0.798	3010.8	250.9	9.26	84.9	21.1	1.56
	105.9	30.98	24.00	7.875	1.102	0.625	2811.5	234.3	9.53	78.9	20.0	1.60
24×7	100.0	29.25	24.00	7.247	0.871	0.747	2371.8	197.6	9.05	48.4	13.4	1.29
	90.0	26.30	24.00	7.124	0.871	0.624	2230.1	185.8	9.21	45.5	12.8	1.32
	79.9	23.33	24.00	7.000	0.871	0.500	2087.2	173.9	9.46	42.9	12.2	1.36
20×7	95.0	27.74	20.00	7.200	0.916	0.800	1599.7	160.0	7.59	50.5	14.0	1.35
	85.0	24.80	20.00	7.053	0.916	0.653	1501.7	150.2	7.78	47.0	13.3	1.38
$20 \times 6\frac{1}{4}$	75.0	21.90	20.00	6.391	0.789	0.641	1263.5	126.3	7.60	30.1	9.4	1.17
	65.4	19.08	20.00	6.250	0.789	0.500	1169.5	116.9	7.83	27.9	8.9	1.21
18×6	70.0	20.46	18.00	6.251	0.691	0.711	917.5	101.9	6.70	24.5	7.8	1.09
	54.7	15.94	18.00	6.000	0.691	0.460	795.5	88.4	7.07	21.2	7.1	1.15
$15 \times 5\frac{1}{2}$	50.0	14.59	15.00	5.640	0.622	0.550	481.1	64.2	5.74	16.0	5.7	1.05
	42.9	12.49	15.00	5.500	0.622	0.410	441.8	58.9	5.95	14.6	5.3	1.08
$12 \times 5\frac{1}{4}$	50.0	14.57	12.00	5.477	0.659	0.687	301.6	50.3	4.55	16.0	5.8	1.05
	40.8	11.84	12.00	5.250	0.659	0.460	268.9	44.8	4.77	13.8	5.3	1.08
12×5	35.0	10.20	12.00	5.078	0.544	0.428	227.0	37.8	4.72	10.0	3.9	0.99
	31.8	9.26	12.00	5.000	0.544	0.350	215.8	36.0	4.83	9.5	3.8	1.01
$10 \times 4\frac{5}{8}$	35.0	10.22	10.00	4.944	0.491	0.594	145.8	29.2	3.78	8.5	3.4	0.91
	25.4	7.38	10.00	4.660	0.491	0.310	122.1	24.4	4.07	6.9	3.0	0.97
8×4	23.0	6.71	8.00	4.171	0.425	0.441	64.2	16.0	3.09	4.4	2.1	0.81
	18.4	5.34	8.00	4.000	0.425	0.270	56.9	14.2	3.26	3.8	1.9	0.84
$7 \times 3\frac{5}{8}$	20.0	5.83	7.00	3.860	0.392	0.450	41.9	12.0	2.68	3.1	1.6	0.74
	15.3	4.43	7.00	3.660	0.392	0.250	36.2	10.4	2.86	2.7	1.5	0.78
$6 \times 3\frac{3}{8}$	17.25	5.02	6.00	3.565	0.359	0.465	26.0	8.7	2.28	2.3	1.3	0.68
	12.5	3.61	6.00	3.330	0.359	0.230	21.8	7.3	2.46	1.8	1.1	0.72
5×3	14.75	4.29	5.00	3.284	0.326	0.494	15.0	6.0	1.87	1.7	1.0	0.63
	10.0	2.87	5.00	3.000	0.326	0.210	12.1	4.8	2.05	1.2	0.82	0.65
$4 \times 2\frac{5}{8}$	9.5	2.76	4.00	2.796	0.293	0.326	6.7	3.3	1.56	0.91	0.65	0.58
	7.7	2.21	4.00	2.660	0.293	0.190	6.0	3.0	1.64	0.77	0.58	0.59
$3 \times 2\frac{3}{8}$	7.5	2.17	3.00	2.509	0.260	0.349	2.9	1.9	1.15	0.59	0.47	0.52
	5.7	1.64	3.00	2.330	0.260	0.170	2.5	1.7	1.23	0.46	0.40	0.53

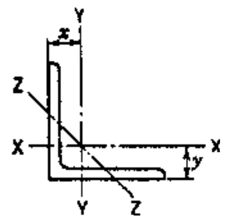
Table 78 Properties of American Standard Channels



Nominal Size (in.)	Weight per Foot (lb)	Area ($in.^2$)	Depth (in.)	Flange Width (in.)	Flange Average Thickness (in.)	Web Thickness (in.)	Axis X–X I ($in.^4$)	Axis X–X S ($in.^3$)	Axis X–X r (in.)	Axis Y–Y I ($in.^4$)	Axis Y–Y S ($in.^3$)	Axis Y–Y r (in.)	Axis Y–Y x (in.)
18×4[a]	58.0	16.98	18.00	4.200	0.625	0.700	670.7	74.5	6.29	18.5	5.6	1.04	0.88
	51.9	15.18	18.00	4.100	0.625	0.600	622.1	69.1	6.40	17.1	5.3	1.06	0.87
	45.8	13.38	18.00	4.000	0.625	0.500	573.5	63.7	6.55	15.8	5.1	1.09	0.89
	42.7	12.48	18.00	3.950	0.625	0.450	549.2	61.0	6.64	15.0	4.9	1.10	0.90
$15 \times 3\frac{3}{8}$	50.0	14.64	15.00	3.716	0.650	0.716	401.4	53.6	5.24	11.2	3.8	0.87	0.80
	40.0	11.70	15.00	3.520	0.650	0.520	346.3	46.2	5.44	9.3	3.4	0.89	0.78
	33.9	9.90	15.00	3.400	0.650	0.400	312.6	41.7	5.62	8.2	3.2	0.91	0.79
12×3	30.0	8.79	12.00	3.170	0.501	0.510	161.2	26.9	4.28	5.2	2.1	0.77	0.68
	25.0	7.32	12.00	3.047	0.501	0.387	143.5	23.9	4.43	4.5	1.9	0.79	0.68
	20.7	6.03	12.00	2.940	0.501	0.280	128.1	21.4	4.61	3.9	1.7	0.81	0.70
$10 \times 2\frac{5}{8}$	30.0	8.80	10.00	3.033	0.436	0.673	103.0	20.6	3.42	4.0	1.7	0.67	0.65
	25.0	7.33	10.00	2.886	0.436	0.526	90.7	18.1	3.52	3.4	1.5	0.68	0.62
	20.0	5.86	10.00	2.739	0.436	0.379	78.5	15.7	3.66	2.8	1.3	0.70	0.61
	15.3	4.47	10.00	2.600	0.436	0.240	66.9	13.4	3.87	2.3	1.2	0.72	0.64
$9 \times 2\frac{1}{2}$	20.0	5.86	9.00	2.648	0.413	0.448	60.6	13.5	3.22	2.4	1.2	0.65	0.59
	15.0	4.39	9.00	2.485	0.413	0.285	50.7	11.3	3.40	1.9	1.0	0.67	0.59
	13.4	3.89	9.00	2.430	0.413	0.230	47.3	10.5	3.49	1.8	0.97	0.67	0.61
$8 \times 2\frac{1}{4}$	18.75	5.49	8.00	2.527	0.390	0.487	43.7	10.9	2.82	2.0	1.0	0.60	0.57
	13.75	4.02	8.00	2.343	0.390	0.303	35.8	9.0	2.99	1.5	0.86	0.62	0.56
	11.5	3.36	8.00	2.260	0.390	0.220	32.3	8.1	3.10	1.3	0.79	0.63	0.58
$7 \times 2\frac{1}{8}$	14.75	4.32	7.00	2.299	0.366	0.419	27.1	7.7	2.51	1.4	0.79	0.57	0.53
	12.25	3.58	7.00	2.194	0.366	0.314	24.1	6.9	2.59	1.2	0.71	0.58	0.53
	9.8	2.85	7.00	2.090	0.366	0.210	21.1	6.0	2.72	0.98	0.63	0.59	0.55
6×2	13.0	3.81	6.00	2.157	0.343	0.437	17.3	5.8	2.13	1.1	0.65	0.53	0.52
	10.5	3.07	6.00	2.034	0.343	0.314	15.1	5.0	2.22	0.87	0.57	0.53	0.50
	8.2	2.39	6.00	1.920	0.343	0.200	13.0	4.3	2.34	0.70	0.50	0.54	0.52
$5 \times 1\frac{3}{4}$	9.0	2.63	5.00	1.885	0.320	0.325	8.8	3.5	1.83	0.64	0.45	0.49	0.48
	6.7	1.95	5.00	1.750	0.320	0.190	7.4	3.0	1.95	0.48	0.38	0.50	0.49
$4 \times 1\frac{5}{8}$	7.25	2.12	4.00	1.720	0.296	0.320	4.5	2.3	1.47	0.44	0.35	0.46	0.46
	5.4	1.56	4.00	1.580	0.296	0.180	3.8	1.9	1.56	0.32	0.29	0.45	0.46
$3 \times 1\frac{1}{2}$	6.0	1.75	3.00	1.596	0.273	0.356	2.1	1.4	1.08	0.31	0.27	0.42	0.46
	5.0	1.46	3.00	1.498	0.273	0.258	1.8	1.2	1.12	0.25	0.24	0.41	0.44
	4.1	1.19	3.00	1.410	0.273	0.170	1.6	1.1	1.17	0.20	0.21	0.41	0.44

[a] Car and Shipbuilding Channel; not an American standard.

Table 79 Properties of Angles with Equal Legs

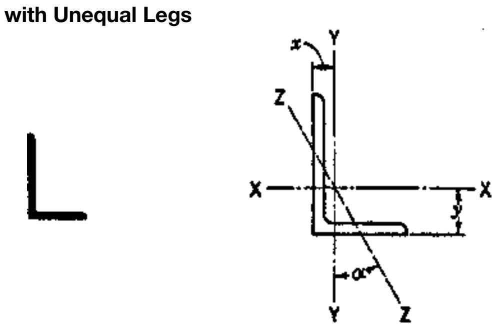


Size (in.)	Thickness (in.)	Weight per Foot (lb)	Area (in.^{2})	Axis X–X and Axis Y–Y I (in.^{4})	S (in.^{3})	r (in.)	x or y (in.)	Axis Z–Z r (in.)
8×8	$1\frac{1}{8}$	56.9	16.73	98.0	17.5	2.42	2.41	1.56
	1	51.0	15.00	89.0	15.8	2.44	2.37	1.56
	$\frac{7}{8}$	45.0	13.23	79.6	14.0	2.45	2.32	1.57
	$\frac{3}{4}$	38.9	11.44	69.7	12.2	2.47	2.28	1.57
	$\frac{5}{8}$	32.7	9.61	59.4	10.3	2.49	2.23	1.58
	$\frac{9}{16}$	29.6	8.68	54.1	9.3	2.50	2.21	1.58
	$\frac{1}{2}$	26.4	7.75	48.6	8.4	2.50	2.19	1.59
6×6	1	37.4	11.00	35.5	8.6	1.80	1.86	1.17
	$\frac{7}{8}$	33.1	9.73	31.9	7.6	1.81	1.82	1.17
	$\frac{3}{4}$	28.7	8.44	28.2	6.7	1.83	1.78	1.17
	$\frac{5}{8}$	24.2	7.11	24.2	5.7	1.84	1.73	1.18
	$\frac{9}{16}$	21.9	6.43	22.1	5.1	1.85	1.71	1.18
	$\frac{1}{2}$	19.6	5.75	19.9	4.6	1.86	1.68	1.18
	$\frac{7}{16}$	17.2	5.06	17.7	4.1	1.87	1.66	1.19
	$\frac{3}{8}$	14.9	4.36	15.4	3.5	1.88	1.64	1.19
	$\frac{5}{16}$	12.5	3.66	13.0	3.0	1.89	1.61	1.19
5×5	$\frac{7}{8}$	27.2	7.98	17.8	5.2	1.49	1.57	0.97
	$\frac{3}{4}$	23.6	6.94	15.7	4.5	1.51	1.52	0.97
	$\frac{5}{8}$	20.0	5.86	13.6	3.9	1.52	1.48	0.98
	$\frac{1}{2}$	16.2	4.75	11.3	3.2	1.54	1.43	0.98
	$\frac{7}{16}$	14.3	4.18	10.0	2.8	1.55	1.41	0.98
	$\frac{3}{8}$	12.3	3.61	8.7	2.4	1.56	1.39	0.99
	$\frac{5}{16}$	10.3	3.03	7.4	2.0	1.57	1.37	0.99
4×4	$\frac{3}{4}$	18.5	5.44	7.7	2.8	1.19	1.27	0.78
	$\frac{5}{8}$	15.7	4.61	6.7	2.4	1.20	1.23	0.78
	$\frac{1}{2}$	12.8	3.75	5.6	2.0	1.22	1.18	0.78
	$\frac{7}{16}$	11.3	3.31	5.0	1.8	1.23	1.16	0.78
	$\frac{3}{8}$	9.8	2.86	4.4	1.5	1.23	1.14	0.79
	$\frac{5}{16}$	8.2	2.40	3.7	1.3	1.24	1.12	0.79
	$\frac{1}{4}$	6.6	1.94	3.0	1.1	1.25	1.09	0.80
$3\frac{1}{2} \times 3\frac{1}{2}$	$\frac{1}{2}$	11.1	3.25	3.6	1.5	1.06	1.06	0.68
	$\frac{7}{16}$	9.8	2.87	3.3	1.3	1.07	1.04	0.68
	$\frac{3}{8}$	8.5	2.48	2.9	1.2	1.07	1.01	0.69
	$\frac{5}{16}$	7.2	2.09	2.5	0.98	1.08	0.99	0.69
	$\frac{1}{4}$	5.8	1.69	2.0	0.79	1.09	0.97	0.69
3×3	$\frac{1}{2}$	9.4	2.75	2.2	1.1	0.90	0.93	0.58
	$\frac{7}{16}$	8.3	2.43	2.0	0.95	0.91	0.91	0.58
	$\frac{3}{8}$	7.2	2.11	1.8	0.83	0.91	0.89	0.58
	$\frac{5}{16}$	6.1	1.78	1.5	0.71	0.92	0.87	0.59

Table 79 (*Continued*)

Size (in.)	Thickness (in.)	Weight per Foot (lb)	Area (in.^{2})	Axis X–X and Axis Y–Y: I (in.^{4})	S (in.^{3})	r (in.)	x or y (in.)	Axis Z–Z: r (in.)
	$\frac{1}{4}$	4.9	1.44	1.2	0.58	0.93	0.84	0.59
	$\frac{3}{16}$	3.71	1.09	0.96	0.44	0.94	0.82	0.59
$2\frac{1}{2} \times 2\frac{1}{2}$	$\frac{1}{2}$	7.7	2.25	1.2	0.72	0.74	0.81	0.49
	$\frac{3}{8}$	5.9	1.73	0.98	0.57	0.75	0.76	0.49
	$\frac{5}{16}$	5.0	1.47	0.85	0.48	0.76	0.74	0.49
	$\frac{1}{4}$	4.1	1.19	0.70	0.39	0.77	0.72	0.49
	$\frac{3}{16}$	3.07	0.90	0.55	0.30	0.78	0.69	0.49
2×2	$\frac{3}{8}$	4.7	1.36	0.48	0.35	0.59	0.64	0.39
	$\frac{5}{16}$	3.92	1.15	0.42	0.30	0.60	0.61	0.39
	$\frac{1}{4}$	3.19	0.94	0.35	0.25	0.61	0.59	0.39
	$\frac{3}{16}$	2.44	0.71	0.27	0.19	0.62	0.57	0.39
	$\frac{1}{8}$	1.65	0.48	0.19	0.13	0.63	0.55	0.40
$1\frac{3}{4} \times 1\frac{3}{4}$	$\frac{1}{4}$	2.77	0.81	0.23	0.19	0.53	0.53	0.34
	$\frac{3}{16}$	2.12	0.62	0.18	0.14	0.54	0.51	0.34
	$\frac{1}{8}$	1.44	0.42	0.13	0.10	0.55	0.48	0.35
$1\frac{1}{2} \times 1\frac{1}{2}$	$\frac{1}{4}$	2.34	0.69	0.14	0.13	0.45	0.47	0.29
	$\frac{3}{16}$	1.80	0.53	0.11	0.10	0.46	0.44	0.29
	$\frac{1}{8}$	1.23	0.36	0.08	0.07	0.47	0.42	0.30
$1\frac{1}{4} \times 1\frac{1}{4}$	$\frac{1}{4}$	1.92	0.56	0.08	0.09	0.37	0.40	0.24
	$\frac{3}{16}$	1.48	0.43	0.06	0.07	0.38	0.38	0.24
	$\frac{1}{8}$	1.01	0.30	0.04	0.05	0.38	0.36	0.25
1×1	$\frac{1}{4}$	1.49	0.44	0.04	0.06	0.29	0.34	0.20
	$\frac{3}{16}$	1.16	0.34	0.03	0.04	0.30	0.32	0.19
	$\frac{1}{8}$	0.80	0.23	0.02	0.03	0.30	0.30	0.20

Table 80 Properties of Angles with Unequal Legs



Size (in.)	Thickness (in.)	Weight per Foot (lb)	Area (in.^{2})	Axis X–X: I (in.^{4})	S (in.^{3})	r (in.)	y (in.)	Axis Y–Y: I (in.^{4})	S (in.^{3})	r (in.)	x (in.)	Axis Z–Z: r (in.)	$\tan\alpha$
9×4	1	40.8	12.00	97.0	17.6	2.84	3.50	12.0	4.0	1.00	1.00	0.83	0.203
	$\frac{7}{8}$	36.1	10.61	86.8	15.7	2.86	3.45	10.8	3.6	1.01	0.95	0.84	0.208
	$\frac{3}{4}$	31.3	9.19	76.1	13.6	2.88	3.41	9.6	3.1	1.02	0.91	0.84	0.212
	$\frac{5}{8}$	26.3	7.73	64.9	11.5	2.90	3.36	8.3	2.6	1.04	0.86	0.85	0.216
	$\frac{9}{16}$	23.8	7.00	59.1	10.4	2.91	3.33	7.6	2.4	1.04	0.83	0.85	0.218
	$\frac{1}{2}$	21.3	6.25	53.2	9.3	2.92	3.31	6.9	2.2	1.05	0.81	0.85	0.220

(*Continues*)

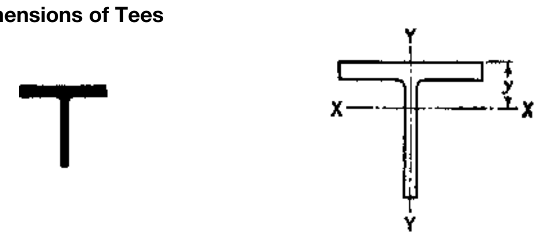
Table 80 (*Continued*)

				Axis X–X				Axis Y–Y				Axis Z–Z	
Size (in.)	Thickness (in.)	Weight per Foot (lb)	Area (in.^{2})	I (in.^{4})	S (in.^{3})	r (in.)	y (in.)	I (in.^{4})	S (in.^{3})	r (in.)	x (in.)	r (in.)	$\tan\alpha$
8×6	1	44.2	13.00	80.8	15.1	2.49	2.65	38.8	8.9	1.73	1.65	1.28	0.543
	$\frac{7}{8}$	39.1	11.48	72.3	13.4	2.51	2.61	34.9	7.9	1.74	1.61	1.28	0.547
	$\frac{3}{4}$	33.8	9.94	63.4	11.7	2.53	2.56	30.7	6.9	1.76	1.56	1.29	0.551
	$\frac{5}{8}$	28.5	8.36	54.1	9.9	2.54	2.52	26.3	5.9	1.77	1.52	1.29	0.554
	$\frac{9}{16}$	25.7	7.56	49.3	9.0	2.55	2.50	24.0	5.3	1.78	1.50	1.30	0.556
	$\frac{1}{2}$	23.0	6.75	44.3	8.0	2.56	2.47	21.7	4.8	1.79	1.47	1.30	0.558
	$\frac{7}{16}$	20.2	5.93	39.2	7.1	2.57	2.45	19.3	4.2	1.80	1.45	1.31	0.560
8×4	1	37.4	11.00	69.6	14.1	2.52	3.05	11.6	3.9	1.03	1.05	0.85	0.247
	$\frac{7}{8}$	33.1	9.73	62.5	12.5	2.53	3.00	10.5	3.5	1.04	1.00	0.85	0.253
	$\frac{3}{4}$	28.7	8.44	54.9	10.9	2.55	2.95	9.4	3.1	1.05	0.95	0.85	0.258
	$\frac{5}{8}$	24.2	7.11	46.9	9.2	2.57	2.91	8.1	2.6	1.07	0.91	0.86	0.262
	$\frac{9}{16}$	21.9	6.43	42.8	8.4	2.58	2.88	7.4	2.4	1.07	0.88	0.86	0.265
	$\frac{1}{2}$	19.6	5.75	38.5	7.5	2.59	2.86	6.7	2.2	1.08	0.86	0.86	0.267
	$\frac{7}{16}$	17.2	5.06	34.1	6.6	2.60	2.83	6.0	1.9	1.09	0.83	0.87	0.269
7×4	$\frac{7}{8}$	30.2	8.86	42.9	9.7	2.20	2.55	10.2	3.5	1.07	1.05	0.86	0.318
	$\frac{3}{4}$	26.2	7.69	37.8	8.4	2.22	2.51	9.1	3.0	1.09	1.01	0.86	0.324
	$\frac{5}{8}$	22.1	6.48	32.4	7.1	2.24	2.46	7.8	2.6	1.10	0.96	0.86	0.329
	$\frac{9}{16}$	20.0	5.87	29.6	6.5	2.24	2.44	7.2	2.4	1.11	0.94	0.87	0.332
	$\frac{1}{2}$	17.9	5.25	26.7	5.8	2.25	2.42	6.5	2.1	1.11	0.92	0.87	0.335
	$\frac{7}{16}$	15.8	4.62	23.7	5.1	2.26	2.39	5.8	1.9	1.12	0.89	0.88	0.337
	$\frac{3}{8}$	13.6	3.98	20.6	4.4	2.27	2.37	5.1	1.6	1.13	0.87	0.88	0.339
6×4	$\frac{7}{8}$	27.2	7.98	27.7	7.2	1.86	2.12	9.8	3.4	1.11	1.12	0.86	0.421
	$\frac{3}{4}$	23.6	6.94	24.5	6.3	1.88	2.08	8.7	3.0	1.12	1.08	0.86	0.428
	$\frac{5}{8}$	20.0	5.86	21.1	5.3	1.90	2.03	7.5	2.5	1.13	1.03	0.86	0.435
	$\frac{9}{16}$	18.1	5.31	19.3	4.8	1.90	2.01	6.9	2.3	1.14	1.01	0.87	0.438
	$\frac{1}{2}$	16.2	4.75	17.4	4.3	1.91	1.99	6.3	2.1	1.15	0.99	0.87	0.440
	$\frac{7}{16}$	14.3	4.18	15.5	3.8	1.92	1.96	5.6	1.9	1.16	0.96	0.87	0.443
	$\frac{3}{8}$	12.3	3.61	13.5	3.3	1.93	1.94	4.9	1.6	1.17	0.94	0.88	0.446
	$\frac{5}{16}$	10.3	3.03	11.4	2.8	1.94	1.92	4.2	1.4	1.17	0.92	0.88	0.449
$6 \times 3\frac{1}{2}$	$\frac{1}{2}$	15.3	4.50	16.6	4.2	1.92	2.08	4.3	1.6	0.97	0.83	0.76	0.344
	$\frac{3}{8}$	11.7	3.42	12.9	3.2	1.94	2.04	3.3	1.2	0.99	0.79	0.77	0.350
	$\frac{5}{16}$	9.8	2.87	10.9	2.7	1.95	2.01	2.9	1.0	1.00	0.76	0.77	0.352
	$\frac{1}{4}$	7.9	2.31	8.9	2.2	1.96	1.99	2.3	0.85	1.01	0.74	0.78	0.355
$5 \times 3\frac{1}{2}$	$\frac{3}{4}$	19.8	5.81	13.9	4.3	1.55	1.75	5.6	2.2	0.98	1.00	0.75	0.464
	$\frac{5}{8}$	16.8	4.92	12.0	3.7	1.56	1.70	4.8	1.9	0.99	0.95	0.75	0.472
	$\frac{1}{2}$	13.6	4.00	10.0	3.0	1.58	1.66	4.1	1.6	1.01	0.91	0.75	0.479
	$\frac{7}{16}$	12.0	3.53	8.9	2.6	1.59	1.63	3.6	1.4	1.01	0.88	0.76	0.482
	$\frac{3}{8}$	10.4	3.05	7.8	2.3	1.60	1.61	3.2	1.2	1.02	0.86	0.76	0.486
	$\frac{5}{16}$	8.7	2.56	6.6	1.9	1.61	1.59	2.7	1.0	1.03	0.84	0.76	0.489
	$\frac{1}{4}$	7.0	2.06	5.4	1.6	1.61	1.56	2.2	0.83	1.04	0.81	0.76	0.492
5×3	$\frac{1}{2}$	12.8	3.75	9.5	2.9	1.59	1.75	2.6	1.1	0.83	0.75	0.65	0.357
	$\frac{7}{16}$	11.3	3.31	8.4	2.6	1.60	1.73	2.3	1.0	0.84	0.73	0.65	0.361
	$\frac{3}{8}$	9.8	2.86	7.4	2.2	1.61	1.70	2.0	0.89	0.84	0.70	0.65	0.364
	$\frac{5}{16}$	8.2	2.40	6.3	1.9	1.61	1.68	1.8	0.75	0.85	0.68	0.66	0.368
	$\frac{1}{4}$	6.6	1.94	5.1	1.5	1.62	1.66	1.4	0.61	0.86	0.66	0.66	0.371
$4 \times 3\frac{1}{2}$	$\frac{5}{8}$	14.7	4.30	6.4	2.4	1.22	1.29	4.5	1.8	1.03	1.04	0.72	0.745
	$\frac{1}{2}$	11.9	3.50	5.3	1.9	1.23	1.25	3.8	1.5	1.04	1.00	0.72	0.750

Table 80 (*Continued*)

		Weight		Axis *X–X*				Axis *Y–Y*				Axis *Z–Z*	
Size (in.)	Thickness (in.)	per Foot (lb)	Area (in.^{2})	I (in.^{4})	S (in.^{3})	r (in.)	y (in.)	I (in.^{4})	S (in.^{3})	r (in.)	x (in.)	r (in.)	$\tan\alpha$
	$\frac{7}{16}$	10.6	3.09	4.8	1.7	1.24	1.23	3.4	1.4	1.05	0.98	0.72	0.753
	$\frac{3}{8}$	9.1	2.67	4.2	1.5	1.25	1.21	3.0	1.2	1.06	0.96	0.73	0.755
	$\frac{5}{16}$	7.7	2.25	3.6	1.3	1.26	1.18	2.6	1.0	1.07	0.93	0.73	0.757
	$\frac{1}{4}$	6.2	1.81	2.9	1.0	1.27	1.16	2.1	0.81	1.07	0.91	0.73	0.759
4×3	$\frac{5}{8}$	13.6	3.98	6.0	2.3	1.23	1.37	2.9	1.4	0.85	0.87	0.64	0.534
	$\frac{1}{2}$	11.1	3.25	5.1	1.9	1.25	1.33	2.4	1.1	0.86	0.83	0.64	0.543
	$\frac{7}{16}$	9.8	2.87	4.5	1.7	1.25	1.30	2.2	1.0	0.87	0.80	0.64	0.547
	$\frac{3}{8}$	8.5	2.48	4.0	1.5	1.26	1.28	1.9	0.87	0.88	0.78	0.64	0.551
	$\frac{5}{16}$	7.2	2.09	3.4	1.2	1.27	1.26	1.7	0.73	0.89	0.76	0.65	0.554
	$\frac{1}{4}$	5.8	1.69	2.8	1.0	1.28	1.24	1.4	0.60	0.90	0.74	0.65	0.558
$3\frac{1}{2} \times 3$	$\frac{1}{2}$	10.2	3.00	3.5	1.5	1.07	1.13	2.3	1.1	0.88	0.88	0.62	0.714
	$\frac{7}{16}$	9.1	2.65	3.1	1.3	1.08	1.10	2.1	0.98	0.89	0.85	0.62	0.718
	$\frac{3}{8}$	7.9	2.30	2.7	1.1	1.09	1.08	1.9	0.85	0.90	0.83	0.62	0.721
	$\frac{5}{16}$	6.6	1.93	2.3	0.95	1.10	1.06	1.6	0.72	0.90	0.81	0.63	0.724
	$\frac{1}{4}$	5.4	1.56	1.9	0.78	1.11	1.04	1.3	0.59	0.91	0.79	0.63	0.727
$3\frac{1}{2} \times 2\frac{1}{2}$	$\frac{1}{2}$	9.4	2.75	3.2	1.4	1.09	1.20	1.4	0.76	0.70	0.70	0.53	0.486
	$\frac{7}{16}$	8.3	2.43	2.9	1.3	1.09	1.18	1.2	0.68	0.71	0.68	0.54	0.491
	$\frac{3}{8}$	7.2	2.11	2.6	1.1	1.10	1.16	1.1	0.59	0.72	0.66	0.54	0.496
	$\frac{5}{16}$	6.1	1.78	2.2	0.93	1.11	1.14	0.94	0.50	0.73	0.64	0.54	0.501
	$\frac{1}{4}$	4.9	1.44	1.8	0.75	1.12	1.11	0.78	0.41	0.74	0.61	0.54	0.506
$3 \times 2\frac{1}{2}$	$\frac{1}{2}$	8.5	2.50	2.1	1.0	0.91	1.00	1.3	0.74	0.72	0.75	0.52	0.667
	$\frac{7}{16}$	7.6	2.21	1.9	0.93	0.92	0.98	1.2	0.66	0.73	0.73	0.52	0.672
	$\frac{3}{8}$	6.6	1.92	1.7	0.81	0.93	0.96	1.0	0.58	0.74	0.71	0.52	0.676
	$\frac{5}{16}$	5.6	1.62	1.4	0.69	0.94	0.93	0.90	0.49	0.74	0.68	0.53	0.680
	$\frac{1}{4}$	4.5	1.31	1.2	0.56	0.95	0.91	0.74	0.40	0.75	0.66	0.53	0.684
3×2	$\frac{1}{2}$	7.7	2.25	1.9	1.0	0.92	1.08	0.67	0.47	0.55	0.58	0.43	0.414
	$\frac{7}{16}$	6.8	2.00	1.7	0.89	0.93	1.06	0.61	0.42	0.55	0.56	0.43	0.421
	$\frac{3}{8}$	5.9	1.73	1.5	0.78	0.94	1.04	0.54	0.37	0.56	0.54	0.43	0.428
	$\frac{5}{16}$	5.0	1.47	1.3	0.66	0.95	1.02	0.47	0.32	0.57	0.52	0.43	0.435
	$\frac{1}{4}$	4.1	1.19	1.1	0.54	0.95	0.99	0.39	0.26	0.57	0.49	0.43	0.440
	$\frac{3}{16}$	3.07	0.90	0.84	0.41	0.97	0.97	0.31	0.20	0.58	0.47	0.44	0.446
$2\frac{1}{2} \times 2$	$\frac{3}{8}$	5.3	1.55	0.91	0.55	0.77	0.83	0.51	0.36	0.58	0.58	0.42	0.614
	$\frac{5}{16}$	4.5	1.31	0.79	0.47	0.78	0.81	0.45	0.31	0.58	0.56	0.42	0.620
	$\frac{1}{4}$	3.62	1.06	0.65	0.38	0.78	0.79	0.37	0.25	0.59	0.54	0.42	0.626
	$\frac{3}{16}$	2.75	0.81	0.51	0.29	0.79	0.76	0.29	0.20	0.60	0.51	0.43	0.631
$2\frac{1}{2} \times 1\frac{1}{2}$	$\frac{3}{8}$	4.7	1.36	0.82	0.52	0.78	0.92	0.22	0.20	0.40	0.42	0.32	0.340
	$\frac{5}{16}$	3.92	1.15	0.71	0.44	0.79	0.90	0.19	0.17	0.41	0.40	0.32	0.349
	$\frac{1}{4}$	3.19	0.94	0.59	0.36	0.79	0.88	0.16	0.14	0.41	0.38	0.32	0.357
	$\frac{3}{16}$	2.44	0.72	0.46	0.28	0.80	0.85	0.13	0.11	0.42	0.35	0.33	0.364
$2 \times 1\frac{1}{2}$	$\frac{1}{4}$	2.77	0.81	0.32	0.24	0.62	0.66	0.15	0.14	0.43	0.41	0.32	0.543
	$\frac{3}{16}$	2.12	0.62	0.25	0.18	0.63	0.64	0.12	0.11	0.44	0.39	0.32	0.551
	$\frac{1}{8}$	1.44	0.42	0.17	0.13	0.64	0.62	0.09	0.08	0.45	0.37	0.33	0.558
$1\frac{3}{4} \times 1\frac{1}{4}$	$\frac{1}{4}$	2.34	0.69	0.20	0.18	0.54	0.60	0.09	0.10	0.35	0.35	0.27	0.486
	$\frac{3}{16}$	1.80	0.53	0.16	0.14	0.55	0.58	0.07	0.08	0.36	0.33	0.27	0.496
	$\frac{1}{8}$	1.23	0.36	0.11	0.09	0.56	0.56	0.05	0.05	0.37	0.31	0.27	0.506

Table 81 Properties and Dimensions of Tees



Tees are seldom used as structural framing members. When so used they are generally employed on short spans in flexure. This table lists a few selected sizes, the range of whose section moduli will cover all ordinary conditions. For sizes not listed, the catalogs of the respective rolling mills should be consulted.

Section Number	Weight per Foot (lb)	Area (in.^{2})	Depth of Tee (in.)	Flange: Width (in.)	Flange: Average Thickness (in.)	Stem Thickness (in.)	Axis $X-X$: I (in.^{4})	Axis $X-X$: S (in.^{3})	Axis $X-X$: r (in.)	Axis $X-X$: y (in.)	Axis $Y-Y$: I (in.^{4})	Axis $Y-Y$: S (in.^{3})	Axis $Y-Y$: r (in.)
ST 18 WF[a]	150	44.09	18.36	16.655	1.680	0.945	1222.7	85.9	5.27	4.13	612.6	73.6	3.73
	140	41.16	18.25	16.595	1.570	0.885	1133.3	79.9	5.25	4.07	563.7	67.9	3.70
	130	38.28	18.12	16.555	1.440	0.845	1059.2	75.4	5.26	4.07	510.3	61.6	3.65
	122.5	36.01	18.03	16.512	1.350	0.802	994.3	71.1	5.25	4.04	472.3	57.2	3.62
	115	33.86	17.94	16.475	1.260	0.765	935.8	67.2	5.26	4.02	435.5	52.9	3.59
ST 18 WF	97	28.56	18.24	12.117	1.260	0.770	904.0	67.3	5.63	4.81	177.7	29.3	2.49
	91	26.77	18.16	12.072	1.180	0.725	844.0	63.0	5.61	4.77	163.9	27.1	2.47
	85	24.99	18.08	12.027	1.100	0.680	784.7	58.8	5.60	4.74	150.3	25.0	2.45
	80	23.54	18.00	12.000	1.020	0.653	741.0	56.0	5.61	4.76	137.7	22.9	2.42
	75	22.08	17.92	11.972	0.940	0.625	696.7	53.0	5.62	4.79	125.2	20.9	2.38
ST 16 WF	120	35.26	16.75	15.865	1.400	0.830	822.5	63.2	4.83	3.73	437.2	55.1	3.52
	110	32.36	16.63	15.810	1.275	0.775	754.1	58.4	4.83	3.71	391.2	49.5	3.48
	100	29.40	16.50	15.750	1.150	0.715	683.6	53.3	4.82	3.67	345.8	43.9	3.43
ST 16 WF	76	22.35	16.75	11.565	1.055	0.635	591.9	47.4	5.15	4.26	128.1	22.1	2.39
	70.5	20.76	16.66	11.535	0.960	0.603	551.8	44.7	5.16	4.30	114.9	19.9	2.35
	65	19.13	16.55	11.510	0.855	0.580	513.0	42.1	5.18	4.37	100.7	17.5	2.29
ST 15 WF	105	30.89	15.19	15.105	1.315	0.775	578.0	48.7	4.33	3.31	354.0	46.9	3.38
	95	27.95	15.06	15.040	1.185	0.710	520.4	44.1	4.31	3.26	312.3	41.5	3.34
	86	25.32	14.94	14.985	1.065	0.655	471.0	40.2	4.31	3.23	275.1	36.7	3.30
ST 15 WF	66	19.41	15.15	10.551	1.000	0.615	420.7	37.4	4.66	3.90	92.5	17.5	2.18
	62	18.22	15.08	10.521	0.930	0.585	394.8	35.3	4.65	3.90	84.8	16.1	2.16
	58.0	17.07	15.00	10.500	0.850	0.564	371.8	33.6	4.67	3.94	76.6	14.6	2.12
	54.0	15.88	14.91	10.484	0.760	0.548	349.5	32.1	4.69	4.03	67.6	12.9	2.06
ST 13 WF	88.5	26.05	13.66	14.090	1.190	0.725	391.8	36.7	3.88	2.97	259.4	36.8	3.16
	80	23.72	13.54	14.023	1.075	0.658	351.4	33.1	3.87	2.91	229.0	32.7	3.12
	72.5	21.34	13.44	13.965	0.975	0.600	316.3	29.9	3.85	2.85	203.5	29.1	3.09
ST 13 WF	57	16.77	13.64	10.070	0.932	0.570	288.9	28.3	4.15	3.42	74.8	14.9	2.11
	51	15.01	13.53	10.018	0.827	0.518	257.7	25.4	4.14	3.39	64.8	12.9	2.08
	47	13.83	13.45	9.990	0.747	0.490	238.5	23.7	4.15	3.41	57.5	11.5	2.04
ST 12 WF	80	23.54	12.36	14.091	1.135	0.656	271.6	27.6	3.40	2.51	246.3	35.0	3.23
	72.5	21.31	12.24	14.043	1.020	0.608	246.2	25.2	3.40	2.48	217.1	30.9	3.19
	65	19.11	12.13	14.000	0.900	0.565	222.6	23.1	3.41	2.47	187.6	26.8	3.13
ST 12 WF	60	17.64	12.16	12.088	0.930	0.556	213.6	22.4	3.48	2.62	127.0	21.0	2.68
	55	16.18	12.08	12.042	0.855	0.510	195.2	20.5	3.47	2.57	114.5	19.0	2.66
	50	14.71	12.00	12.000	0.775	0.468	176.7	18.7	3.46	2.54	101.8	17.0	2.63
ST 12 WF	47	13.81	12.15	9.061	0.872	0.516	185.9	20.3	3.67	2.99	51.1	11.3	1.92
	42	12.35	12.04	9.015	0.772	0.470	165.9	18.3	3.66	2.97	44.2	9.8	1.89
	38	11.18	11.95	8.985	0.682	0.440	151.1	16.9	3.68	3.00	38.3	8.5	1.85
ST 10 WF	71	20.88	10.73	13.132	1.095	0.659	177.3	20.8	2.91	2.18	193.0	29.4	3.04
	63.5	18.67	10.62	13.061	0.985	0.588	155.8	18.3	2.89	2.11	169.3	25.9	3.01
	56	16.47	10.50	13.000	0.865	0.527	136.4	16.2	2.88	2.06	144.8	22.3	2.96
ST 10 WF[a]	48	14.11	10.57	9.038	0.935	0.575	137.1	17.1	3.11	2.55	54.7	12.1	1.97
	41	12.05	10.43	8.962	0.795	0.499	115.4	14.5	3.09	2.48	44.8	10.0	1.93

Table 81 **(*Continued*)**

				Flange			Axis X–X				Axis Y–Y		
Section Number	Weight per Foot (lb)	Area (in.^{2})	Depth of Tee (in.)	Width (in.)	Average Thickness (in.)	Stem Thickness (in.)	I (in.^{4})	S (in.^{3})	r (in.)	y (in.)	I (in.^{4})	S (in.^{3})	r (in.)
ST 10 WF	36.5	10.73	10.62	8.295	0.740	0.455	110.2	13.7	3.21	2.60	33.1	7.98	1.76
	34	10.01	10.57	8.270	0.685	0.430	102.8	12.9	3.20	2.59	30.2	7.30	1.74
	31	9.12	10.49	8.240	0.615	0.400	93.7	11.9	3.21	2.59	26.6	6.45	1.71
ST 9 WF	57	16.77	9.24	11.833	0.991	0.595	102.6	13.9	2.47	1.85	127.8	21.6	2.76
	52.5	15.43	9.16	11.792	0.911	0.554	93.9	12.8	2.47	1.82	115.5	19.6	2.73
	48	14.11	9.08	11.750	0.831	0.512	85.3	11.7	2.46	1.78	103.4	17.6	2.71
ST 9 WF	42.5	12.49	9.16	8.838	0.911	0.526	84.4	11.9	2.60	2.05	49.7	11.3	2.00
	38.5	11.32	9.08	8.787	0.831	0.475	75.3	10.6	2.58	1.99	44.3	10.1	1.98
	35	10.28	9.00	8.750	0.751	0.438	68.1	9.67	2.57	1.96	39.2	8.97	1.95
	32	9.40	8.94	8.715	0.686	0.403	61.8	8.82	2.56	1.93	35.2	8.07	1.93
ST 9 WF	30	8.82	9.12	7.558	0.695	0.416	64.8	9.32	2.71	2.17	23.5	6.23	1.63
	27.5	8.09	9.06	7.532	0.630	0.390	59.6	8.63	2.71	2.16	21.0	5.57	1.61
	25	7.35	9.00	7.500	0.570	0.358	53.9	7.85	2.71	2.14	18.6	4.96	1.59
ST 8 WF	48	14.11	8.16	11.533	0.875	0.535	64.7	9.82	2.14	1.57	103.6	18.0	2.71
	44	12.94	8.08	11.502	0.795	0.504	59.5	9.11	2.14	1.55	92.6	16.1	2.67
ST 8 WF	39	11.46	8.16	8.586	0.875	0.529	60.0	9.45	2.28	1.81	43.8	10.2	1.95
	35.5	10.43	8.08	8.543	0.795	0.486	54.0	8.57	2.28	1.77	38.9	9.11	1.93
	32	9.40	8.00	8.500	0.715	0.443	48.3	7.71	2.27	1.73	34.2	8.05	1.91
	29	8.52	7.93	8.464	0.645	0.407	43.6	7.00	2.26	1.70	30.2	7.14	1.88
ST 8 WF	25	7.35	8.13	7.073	0.628	0.380	42.2	6.77	2.40	1.89	17.4	4.92	1.54
	22.5	6.62	8.06	7.039	0.563	0.346	37.8	6.10	2.39	1.87	15.2	4.33	1.52
	20	5.88	8.00	7.000	0.503	0.307	33.2	5.37	2.37	1.82	13.3	3.79	1.50
	18	5.30	7.93	6.992	0.428	0.299	30.7	5.10	2.41	1.90	11.1	3.17	1.45
ST 7 WF	105.5	31.04	7.88	15.800	1.563	0.980	102.2	16.2	1.81	1.57	514.3	65.1	4.07
	101	29.70	7.82	15.750	1.503	0.930	95.7	15.2	1.80	1.53	489.8	62.2	4.06
	96.5	28.36	7.75	15.710	1.438	0.890	90.1	14.4	1.78	1.49	465.1	59.2	4.05
	92	27.04	7.69	15.660	1.378	0.840	83.9	13.4	1.76	1.45	441.4	56.4	4.04
	88	25.87	7.63	15.640	1.313	0.820	80.2	12.9	1.76	1.42	418.9	53.6	4.02
	83.5	24.55	7.56	15.600	1.248	0.780	75.0	12.1	1.75	1.39	395.1	50.7	4.01
	79	23.24	7.50	15.550	1.188	0.730	69.3	11.3	1.73	1.34	372.5	47.9	4.00
	75	22.04	7.44	15.515	1.128	0.695	64.9	10.6	1.72	1.31	351.3	45.3	3.99
	71	20.92	7.38	15.500	1.063	0.680	62.1	10.2	1.72	1.29	330.1	42.6	3.97
ST 7 WF	68	19.99	7.38	14.740	1.063	0.660	60.0	9.89	1.73	1.31	283.9	38.5	3.77
	63.5	18.67	7.31	14.690	0.998	0.610	54.7	9.04	1.71	1.26	263.8	35.9	3.76
	59.5	17.49	7.25	14.650	0.938	0.570	50.4	8.36	1.70	1.22	245.9	33.6	3.75
	55.5	16.33	7.19	14.620	0.873	0.540	46.7	7.80	1.69	1.19	227.4	31.1	3.73
	51.5	15.13	7.13	14.575	0.813	0.495	42.4	7.10	1.67	1.15	209.9	28.8	3.72
	47.5	13.97	7.06	14.545	0.748	0.465	39.1	6.58	1.67	1.12	191.9	26.4	3.71
	43.5	12.78	7.00	14.5	0.688	0.420	34.9	5.88	1.65	1.08	174.8	24.1	3.70
ST 7 WF	42	12.36	7.09	12.023	0.778	0.451	37.4	6.36	1.74	1.21	112.7	18.8	3.02
	39	11.47	7.03	12.000	0.718	0.428	34.8	5.96	1.74	1.19	103.5	17.2	3.00
ST 7 WF	37	10.88	7.10	10.072	0.783	0.450	36.1	6.26	1.82	1.32	66.7	13.3	2.48
	34	10.00	7.03	10.040	0.718	0.418	33.0	5.74	1.81	1.29	60.6	12.1	2.46
	30.5	8.97	6.96	10.000	0.643	0.378	29.2	5.13	1.80	1.25	53.6	10.7	2.45
ST 7 WF	26.5	7.79	6.97	8.062	0.658	0.370	27.7	4.95	1.88	1.38	28.8	7.14	1.92
	24	7.06	6.91	8.031	0.593	0.339	24.9	4.49	1.88	1.35	25.6	6.38	1.91
	21.5	6.32	6.84	8.000	0.528	0.308	22.2	4.02	1.87	1.33	22.6	5.64	1.89
ST 7 WF[a]	19	5.59	7.06	6.776	0.513	0.313	23.5	4.27	2.05	1.56	12.3	3.64	1.49
	17	5.00	7.00	6.750	0.453	0.287	21.1	3.86	2.05	1.55	10.6	3.15	1.46
	15	4.41	6.93	6.733	0.383	0.270	19.0	3.55	2.08	1.59	8.77	2.61	1.41
ST 6 WF	80.5	23.69	6.94	12.515	1.486	0.905	62.6	11.5	1.63	1.47	243.1	38.9	3.20
	66.5	19.56	6.69	12.365	1.236	0.755	48.4	9.03	1.57	1.33	195.0	31.5	3.16
	60	17.65	6.56	12.320	1.106	0.710	43.4	8.22	1.57	1.28	172.5	28.0	3.13
	53	15.59	6.44	12.230	0.986	0.620	36.7	7.01	1.53	1.20	150.4	24.6	3.11
	49.5	14.54	6.38	12.190	0.921	0.580	33.7	6.46	1.52	1.16	139.1	22.8	3.09

Table 81 (*Continued*)

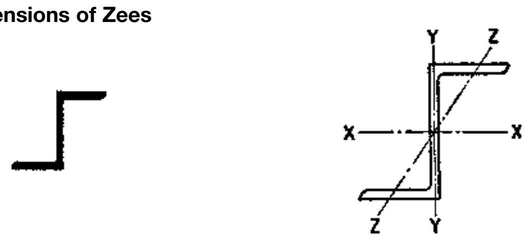
				Flange			Axis *X–X*				Axis *Y–Y*		
Section Number	Weight per Foot (lb)	Area (in.^{2})	Depth of Tee (in.)	Width (in.)	Average Thickness (in.)	Stem Thickness (in.)	*I* (in.^{4})	*S* (in.^{3})	*r* (in.)	*y* (in.)	*I* (in.^{4})	*S* (in.^{3})	*r* (in.)
	46	13.53	6.31	12.155	0.856	0.545	31.0	5.98	1.51	1.13	128.2	21.1	3.08
	42.5	12.49	6.25	12.105	0.796	0.495	27.8	5.38	1.49	1.08	117.7	19.5	3.07
	39.5	11.61	6.19	12.080	0.736	0.470	25.8	5.02	1.48	1.06	108.2	17.9	3.05
	36	10.58	6.13	12.040	0.671	0.430	23.1	4.53	1.48	1.02	97.6	16.2	3.04
	32.5	9.55	6.06	12.000	0.606	0.390	20.6	4.06	1.47	0.98	87.3	14.6	3.02
ST 6 WF	29	8.53	6.10	10.014	0.641	0.359	19.0	3.75	1.49	1.03	53.7	10.7	2.51
	26.5	7.80	6.03	10.000	0.576	0.345	17.7	3.54	1.51	1.02	48.0	9.60	2.48
ST 6 WF	25	7.36	6.10	8.077	0.641	0.371	18.7	3.80	1.60	1.17	28.2	6.98	1.96
	22.5	6.62	6.03	8.042	0.576	0.336	16.6	3.40	1.59	1.13	25.0	6.20	1.94
	20	5.89	5.97	8.000	0.516	0.294	14.4	2.94	1.56	1.08	22.0	5.50	1.94
ST 6 WF	18	5.29	6.12	6.565	0.540	0.305	15.3	3.14	1.70	1.26	11.9	3.62	1.50
	15.5	4.56	6.04	6.525	0.465	0.265	13.0	2.69	1.69	1.22	9.9	3.04	1.47
	13.5	3.98	5.98	6.500	0.400	0.240	11.4	2.39	1.69	1.21	8.3	2.55	1.44
ST 6 WF	7	2.07	5.96	3.970	0.224	0.200	7.66	1.83	1.92	1.76	1.13	0.57	0.74
ST 6 I[b]	25	7.29	6.00	5.477	0.660	0.687	25.2	6.05	1.85	1.84	7.85	2.87	1.03
	20.4	5.92	6.00	5.250	0.660	0.460	18.8	4.26	1.77	1.57	6.77	2.58	1.06
ST 6 I	17.5	5.10	6.00	5.078	0.544	0.428	17.2	3.95	1.83	1.65	4.93	1.94	0.98
	15.9	4.63	6.00	5.000	0.544	0.350	14.9	3.31	1.78	1.51	4.68	1.87	1.00
ST 5 I	17.5	5.11	5.00	4.944	0.491	0.594	12.5	3.63	1.56	1.56	4.18	1.69	0.90
	12.7	3.69	5.00	4.660	0.491	0.310	7.81	2.05	1.45	1.20	3.39	1.46	0.95
ST 4 I	11.5	3.36	4.00	4.171	0.425	0.441	5.03	1.77	1.22	1.15	2.15	1.03	0.80
	9.2	2.67	4.00	4.000	0.425	0.270	3.50	1.14	1.14	0.94	1.86	0.93	0.83
ST 3.5 I	10	2.92	3.50	3.860	0.392	0.450	3.36	1.36	1.07	1.04	1.58	0.82	0.73
	7.65	2.22	3.50	3.660	0.392	0.250	2.18	0.81	0.99	0.81	1.32	0.72	0.77
ST 3 I	8.625	2.51	3.00	3.565	0.359	0.465	2.13	1.02	0.92	0.91	1.15	0.65	0.67
	6.25	1.81	3.00	3.330	0.359	0.230	1.27	0.55	0.83	0.69	0.93	0.56	0.71
ST 5 WF	56	16.46	5.69	10.415	1.248	0.755	28.8	6.42	1.32	1.21	117.7	22.6	2.67
	50	14.72	5.56	10.345	1.118	0.685	24.8	5.62	1.30	1.14	103.3	20.0	2.65
	44.5	13.09	5.44	10.275	0.998	0.615	21.3	4.88	1.28	1.07	90.3	17.6	2.63
	38.5	11.33	5.31	10.195	0.868	0.535	17.7	4.10	1.25	1.00	76.7	15.1	2.60
	36	10.59	5.25	10.170	0.808	0.510	16.4	3.83	1.24	0.97	70.9	13.9	2.59
	33	9.70	5.19	10.117	0.748	0.457	14.5	3.39	1.22	0.92	64.6	12.8	2.58
	30	8.83	5.13	10.075	0.683	0.415	12.8	3.02	1.21	0.88	58.2	11.6	2.57
	27	7.94	5.06	10.028	0.618	0.368	11.2	2.64	1.18	0.84	51.95	10.4	2.56
	24.5	7.20	5.00	10.000	0.558	0.340	10.1	2.40	1.18	0.81	46.5	9.30	2.54
ST 5 WF	22.5	6.62	5.06	8.022	0.618	0.350	10.3	2.48	1.25	0.91	26.6	6.63	2.00
	19.5	5.74	4.97	7.990	0.528	0.318	8.96	2.19	1.25	0.88	22.5	5.62	1.98
	16.5	4.85	4.88	7.964	0.433	0.292	7.80	1.95	1.27	0.88	18.2	4.58	1.94
ST 5 WF[a]	14.5	4.27	5.11	5.799	0.500	0.289	8.38	2.07	1.40	1.05	7.61	2.62	1.34
	12.5	3.67	5.04	5.762	0.430	0.252	7.12	1.77	1.39	1.02	6.34	2.20	1.31
	10.5	3.10	4.95	5.750	0.340	0.240	6.31	1.62	1.43	1.06	4.87	1.69	1.25
ST 4 WF	33.5	9.85	4.50	8.287	0.933	0.575	10.94	3.07	1.05	0.94	44.3	10.7	2.12
	29	8.53	4.38	8.222	0.808	0.510	9.11	2.60	1.03	0.87	37.5	9.10	2.10
	24	7.06	4.25	8.117	0.683	0.405	6.92	2.00	0.99	0.78	30.45	7.50	2.08
	20	5.88	4.13	8.077	0.558	0.365	5.80	1.71	0.99	0.74	24.5	6.05	2.04
	17.5	5.15	4.06	8.027	0.493	0.315	4.88	1.45	0.97	0.69	21.25	5.30	2.03
	15.5	4.56	4.00	8.000	0.433	0.288	4.31	1.30	0.97	0.67	18.5	4.60	2.01
ST 4 WF	14	4.11	4.03	6.540	0.463	0.285	4.22	1.28	1.01	0.73	10.8	3.30	1.62
	12	3.53	3.97	6.500	0.398	0.245	3.53	1.08	1.00	0.70	9.10	2.80	1.61
ST 4 WF	10	2.94	4.07	5.268	0.378	0.248	3.66	1.13	1.12	0.83	4.25	1.61	1.20
	8.5	2.50	4.00	5.250	0.308	0.230	3.21	1.01	1.13	0.84	3.36	1.28	1.16

Table 81 (*Continued*)

Nominal Size (in.)	Weight per Foot (lb)	Area (in.^{2})	Dimensions: Depth (in.)	Dimensions: Width Flange (in.)	Dimensions: Minimum Flange (in.)	Dimensions: Thickness Stem (in.)	Axis X–X: I (in.^{4})	Axis X–X: S (in.^{3})	Axis X–X: r (in.)	Axis X–X: y (in.)	Axis Y–Y: I (in.^{4})	Axis Y–Y: S (in.^{3})	Axis Y–Y: r (in.)
$5 \times 3\frac{1}{8}$	13.6	4.00	$3\frac{1}{8}$	5	$\frac{1}{2}$	$\frac{13}{32}$	2.7	1.1	0.82	0.76	5.2	2.1	1.14
5×3	11.5	3.37	3	5	$\frac{3}{8}$	$\frac{13}{32}$	2.4	1.1	0.84	0.76	3.9	1.6	1.10
$4 \times 4\frac{1}{2}$	11.2	3.29	$4\frac{1}{2}$	4	$\frac{3}{8}$	$\frac{3}{8}$	6.3	2.0	1.39	1.31	2.1	1.1	0.80
4×4	13.5	3.97	4	4	$\frac{1}{2}$	$\frac{1}{2}$	5.7	2.0	1.20	1.18	2.8	1.4	0.84
4×3	9.2	2.68	3	4	$\frac{3}{8}$	$\frac{3}{8}$	2.0	0.90	0.86	0.78	2.1	1.1	0.89
$4 \times 2\frac{1}{2}$	8.5	2.48	$2\frac{1}{2}$	4	$\frac{3}{8}$	$\frac{3}{8}$	1.2	0.62	0.69	0.62	2.1	1.0	0.92
3×3	7.8	2.29	3	3	$\frac{3}{8}$	$\frac{3}{8}$	1.84	0.86	0.89	0.88	0.89	0.60	0.63
3×3	6.7	1.97	3	3	$\frac{5}{16}$	$\frac{5}{16}$	1.61	0.74	0.90	0.85	0.75	0.50	0.62
$3 \times 2\frac{1}{2}$	6.1	1.77	$2\frac{1}{2}$	3	$\frac{5}{16}$	$\frac{5}{16}$	0.94	0.51	0.73	0.68	0.75	0.50	0.65
$2\frac{1}{2} \times 2\frac{1}{2}$	6.4	1.87	$2\frac{1}{2}$	$2\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	1.0	0.59	0.74	0.76	0.52	0.42	0.53
$2\frac{1}{2} \times 2\frac{1}{2}$	4.6	1.33	$2\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	0.74	0.42	0.75	0.71	0.34	0.27	0.51
$2\frac{1}{4} \times 2\frac{1}{4}$	4.1	1.19	$2\frac{1}{4}$	$2\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	0.52	0.32	0.66	0.65	0.25	0.22	0.46
2×2	4.3	1.26	2	2	$\frac{5}{16}$	$\frac{5}{16}$	0.44	0.31	0.59	0.61	0.23	0.23	0.43
2×2	3.56	1.05	2	2	$\frac{1}{4}$	$\frac{1}{4}$	0.37	0.26	0.59	0.59	0.18	0.18	0.42

[a] WF indicates structural tee cut from wide-flange section.
[b] I indicates structural tee cut from standard beam section.

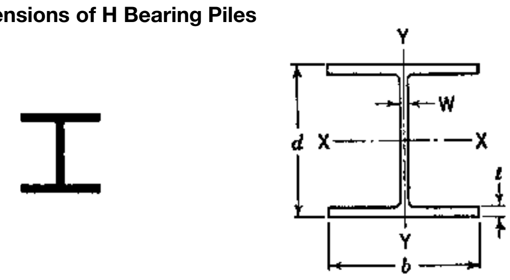
Table 82 Properties and Dimensions of Zees



Zees are seldom used as structural framing members. When so used they are generally employed on short spans in flexure. This table lists a few selected sizes, the range of whose section moduli will cover all ordinary conditions. For sizes not listed, the catalogs of the respective rolling mills should be consulted.

Nominal Size (in.)	Weight per Foot (lb)	Area (in.^{2})	Dimensions: Depth (in.)	Dimensions: Width of Flange (in.)	Dimensions: Thickness (in.)	Axis X–X: I (in.^{4})	Axis X–X: S (in.^{3})	Axis X–X: r (in.)	Axis Y–Y: I (in.^{4})	Axis Y–Y: S (in.^{3})	Axis Y–Y: r (in.)	Axis Z–Z: r (in.)
$6 \times 3\frac{1}{2}$	21.1	6.19	$6\frac{1}{8}$	$3\frac{5}{8}$	$\frac{1}{2}$	34.4	11.2	2.36	12.9	3.8	1.44	0.84
	15.7	4.59	6	$3\frac{1}{2}$	$\frac{3}{8}$	25.3	8.4	2.35	9.1	2.8	1.41	0.83
$5 \times 3\frac{1}{4}$	17.9	5.25	5	$3\frac{1}{4}$	$\frac{1}{2}$	19.2	7.7	1.91	9.1	3.0	1.31	0.74
	16.4	4.81	$5\frac{1}{8}$	$3\frac{3}{8}$	$\frac{7}{16}$	19.1	7.4	1.99	9.2	2.9	1.38	0.77
	14.0	4.10	$5\frac{1}{16}$	$3\frac{5}{16}$	$\frac{3}{8}$	16.2	6.4	1.99	7.7	2.5	1.37	0.76
	11.6	3.40	5	$3\frac{1}{4}$	$\frac{5}{16}$	13.4	5.3	1.98	6.2	2.0	1.35	0.75
$4 \times 3\frac{1}{16}$	15.9	4.66	$4\frac{1}{16}$	$3\frac{1}{8}$	$\frac{1}{2}$	11.2	5.5	1.55	8.0	2.8	1.31	0.67
	12.5	3.66	$4\frac{1}{8}$	$3\frac{3}{16}$	$\frac{3}{8}$	9.6	4.7	1.62	6.8	2.3	1.36	0.69
	10.3	3.03	$4\frac{1}{16}$	$3\frac{1}{8}$	$\frac{5}{16}$	7.9	3.9	1.62	5.5	1.8	1.34	0.68
	8.2	2.41	4	$3\frac{1}{16}$	$\frac{1}{4}$	6.3	3.1	1.62	4.2	1.4	1.33	0.67
$3 \times 2\frac{11}{16}$	12.6	3.69	3	$2\frac{11}{16}$	$\frac{1}{2}$	4.6	3.1	1.12	4.9	2.0	1.15	0.53
	9.8	2.86	3	$2\frac{11}{16}$	$\frac{3}{8}$	3.9	2.6	1.16	3.9	1.6	1.17	0.54
	6.7	1.97	3	$2\frac{11}{16}$	$\frac{1}{4}$	2.9	1.9	1.21	2.8	1.1	1.19	0.55

Table 83 Properties and Dimensions of H Bearing Piles



Section Number and Nominal Size	Weight per Foot (lb)	Area A (in.^{2})	Depth d (in.)	Flange Width b (in.)	Flange Thickness t (in.)	Web Thickness W (in.)	Axis X–X I (in.^{4})	Axis X–X S (in.^{3})	Axis X–X r (in.)	Axis Y–Y I' (in.^{4})	Axis Y–Y S' (in.^{3})	Axis Y–Y r' (in.)
BP 14,	117	34.44	14.234	14.885	0.805	0.805	1228.5	172.6	5.97	443.1	59.5	3.59
$14 \times 14\frac{1}{2}$	102	30.01	14.032	14.784	0.704	0.704	1055.1	150.4	5.93	379.6	51.3	3.56
	89	26.19	13.856	14.696	0.616	0.616	909.1	131.2	5.89	326.2	44.4	3.53
	73	21.46	13.636	14.586	0.506	0.506	733.1	107.5	5.85	261.9	35.9	3.49
BP 12,	74	21.76	12.122	12.217	0.607	0.607	566.5	93.5	5.10	184.7	30.2	2.91
12×12	53	15.58	11.780	12.046	0.436	0.436	394.8	67.0	5.03	127.3	21.2	2.86
BP 10,	57	16.76	10.012	10.224	0.564	0.564	294.7	58.9	4.19	100.6	19.7	2.45
10×10	42	12.35	9.720	10.078	0.418	0.418	210.8	43.4	4.13	71.4	14.2	2.40
BP 8,												
8×8	36	10.60	8.026	8.158	0.446	0.446	119.8	29.9	3.36	40.4	9.9	1.95

Table 84 Square and Round Bars[a]

Size (in.)	Square Weight/ft (lb)	Square Area (in.^{2})	Round Weight/ft (lb)	Round Area (in.^{2})	Size (in.)	Square Weight/ft (lb)	Square Area (in.^{2})	Round Weight/ft (lb)	Round Area (in.^{2})
0					$\frac{5}{16}$	5.857	1.7227	4.600	1.3530
$\frac{1}{16}$	0.013	0.0039	0.010	0.0031	$\frac{3}{8}$	6.428	1.8906	5.049	1.4849
$\frac{1}{8}$	0.053	0.0156	0.042	0.0123	$\frac{7}{16}$	7.026	2.0664	5.518	1.6230
$\frac{3}{16}$	0.120	0.0352	0.094	0.0276	$\frac{1}{2}$	7.650	2.2500	6.008	1.7671
$\frac{1}{4}$	0.213	0.0625	0.167	0.0491	$\frac{9}{16}$	8.301	2.4414	6.519	1.9175
$\frac{5}{16}$	0.332	0.0977	0.261	0.0767	$\frac{5}{8}$	8.978	2.6406	7.051	2.0739
$\frac{3}{8}$	0.478	0.1406	0.376	0.1105	$\frac{11}{16}$	9.682	2.8477	7.604	2.2365
$\frac{7}{16}$	0.651	0.1914	0.511	0.1503	$\frac{3}{4}$	10.413	3.0625	8.178	2.4053
$\frac{1}{2}$	0.850	0.2500	0.668	0.1963	$\frac{13}{16}$	11.170	3.2852	8.773	2.5802
$\frac{9}{16}$	1.076	0.3164	0.845	0.2485	$\frac{7}{8}$	11.953	3.5156	9.388	2.7612
$\frac{5}{8}$	1.328	0.3906	1.043	0.3068	$\frac{15}{16}$	12.763	3.7539	10.024	2.9483
$\frac{11}{16}$	1.607	0.4727	1.262	0.3712	2	13.600	4.0000	10.681	3.1416
$\frac{3}{4}$	1.913	0.5625	1.502	0.4418	$\frac{1}{16}$	14.463	4.2539	11.359	3.3410
$\frac{13}{16}$	2.245	0.6602	1.763	0.5185	$\frac{1}{8}$	15.353	4.5156	12.058	3.5466
$\frac{7}{8}$	2.603	0.7656	2.044	0.6013	$\frac{3}{16}$	16.270	4.7852	12.778	3.7583
$\frac{15}{16}$	2.988	0.8789	2.347	0.6903	$\frac{1}{4}$	17.213	5.0625	13.519	3.9761
1	3.400	1.0000	2.670	0.7854	$\frac{5}{16}$	18.182	5.3477	14.280	4.2000
$\frac{1}{16}$	3.838	1.1289	3.015	0.8866	$\frac{3}{8}$	19.178	5.6406	15.062	4.4301
$\frac{1}{8}$	4.303	1.2656	3.380	0.9940	$\frac{7}{16}$	20.201	5.9414	15.866	4.6664
$\frac{3}{16}$	4.795	1.4102	3.766	1.1075	$\frac{1}{2}$	21.250	6.2500	16.690	4.9087
$\frac{1}{4}$	5.313	1.5625	4.172	1.2272	$\frac{9}{16}$	22.326	6.5664	17.534	5.1572

Table 84 (*Continued*)

	Square		Round	
Size (in.)	Weight/ft (lb)	Area (in.^{2})	Weight/ft (lb)	Area (in.^{2})
$\frac{5}{8}$	23.428	6.8906	18.400	5.4119
$\frac{11}{16}$	24.557	7.2227	19.287	5.6727
$\frac{3}{4}$	25.713	7.5625	20.195	5.9396
$\frac{13}{16}$	26.895	7.9102	21.123	6.2126
$\frac{7}{8}$	28.103	8.2656	22.072	6.4918
$\frac{15}{16}$	29.338	8.6289	23.042	6.7771
3	30.60	9.000	24.03	7.069
$\frac{1}{16}$	31.89	9.379	25.05	7.366
$\frac{1}{8}$	33.20	9.766	26.08	7.670
$\frac{3}{16}$	34.54	10.160	27.13	7.980
$\frac{1}{4}$	35.91	10.563	28.21	8.296
$\frac{5}{16}$	37.31	10.973	29.30	8.618
$\frac{3}{8}$	38.73	11.391	30.42	8.946
$\frac{7}{16}$	40.18	11.816	31.55	9.281
$\frac{1}{2}$	41.65	12.250	32.71	9.621
$\frac{9}{16}$	43.15	12.691	33.89	9.968
$\frac{5}{8}$	44.68	13.141	35.09	10.321
$\frac{11}{16}$	46.23	13.598	36.31	10.680
$\frac{3}{4}$	47.81	14.063	37.55	11.045
$\frac{13}{16}$	49.42	14.535	38.81	11.416
$\frac{7}{8}$	51.05	15.016	40.10	11.793
$\frac{15}{16}$	52.71	15.504	41.40	12.177
4	54.40	16.000	42.73	12.566
$\frac{1}{16}$	56.11	16.504	44.07	12.962
$\frac{1}{8}$	57.85	17.016	45.44	13.364
$\frac{3}{16}$	59.62	17.535	46.83	13.772
$\frac{1}{4}$	61.41	18.063	48.23	14.186
$\frac{5}{16}$	63.23	18.598	49.66	14.607
$\frac{3}{8}$	65.08	19.141	51.11	15.033
$\frac{7}{16}$	66.95	19.691	52.58	15.466
$\frac{1}{2}$	68.85	20.250	54.07	15.904
$\frac{9}{16}$	70.78	20.816	55.59	16.349
$\frac{5}{8}$	72.73	21.391	57.12	16.800
$\frac{11}{16}$	74.71	21.973	58.67	17.257
$\frac{3}{4}$	76.71	22.563	60.25	17.721
$\frac{13}{16}$	78.74	23.160	61.85	18.190
$\frac{7}{8}$	80.80	23.766	63.46	18.665
$\frac{15}{16}$	82.89	24.379	65.10	19.147
5	85.00	25.000	66.76	19.635
$\frac{1}{16}$	87.14	25.629	68.44	20.129
$\frac{1}{8}$	89.30	26.266	70.14	20.629
$\frac{3}{16}$	91.49	26.910	71.86	21.135
$\frac{1}{4}$	93.71	27.563	73.60	21.648
$\frac{5}{16}$	95.96	28.223	75.36	22.166
$\frac{3}{8}$	98.23	28.891	77.15	22.691
$\frac{7}{16}$	100.53	29.566	78.95	23.221
$\frac{1}{2}$	102.85	30.250	80.78	23.758
$\frac{9}{16}$	105.20	30.941	82.62	24.301
$\frac{5}{8}$	107.58	31.641	84.49	24.850
$\frac{11}{16}$	109.98	32.348	86.38	25.406
$\frac{3}{4}$	112.41	33.063	88.29	25.967
$\frac{13}{16}$	114.87	33.785	90.22	26.535
$\frac{7}{8}$	117.35	34.516	92.17	27.109
$\frac{15}{16}$	119.86	35.254	94.14	27.688
6	122.40	36.000	96.13	28.274
$\frac{1}{16}$	124.96	36.754	98.15	28.866
$\frac{1}{8}$	127.55	37.516	100.18	29.465
$\frac{3}{16}$	130.17	38.285	102.23	30.069
$\frac{1}{4}$	132.81	39.063	104.31	30.680
$\frac{5}{16}$	135.48	39.848	106.41	31.296
$\frac{3}{8}$	138.18	40.641	108.53	31.919
$\frac{7}{16}$	140.90	41.441	110.66	32.548
$\frac{1}{2}$	143.65	42.250	112.82	33.183
$\frac{9}{16}$	146.43	43.066	115.00	33.824
$\frac{5}{8}$	149.23	43.891	117.20	34.472
$\frac{11}{16}$	152.06	44.723	119.43	35.125
$\frac{3}{4}$	154.91	45.563	121.67	35.785
$\frac{13}{16}$	157.79	46.410	123.93	36.450
$\frac{7}{8}$	160.70	47.266	126.22	37.122
$\frac{15}{16}$	163.64	48.129	128.52	37.800
7	166.60	49.000	130.85	38.485
$\frac{1}{16}$	169.59	49.879	133.19	39.175
$\frac{1}{8}$	172.60	50.766	135.56	39.871
$\frac{3}{16}$	175.64	51.660	137.95	40.574
$\frac{1}{4}$	178.71	52.563	140.36	41.282
$\frac{5}{16}$	181.81	53.473	142.79	41.997
$\frac{3}{8}$	184.93	54.391	145.24	42.718
$\frac{7}{16}$	188.07	55.316	147.71	43.445
$\frac{1}{2}$	191.25	56.250	150.21	44.179
$\frac{9}{16}$	194.45	57.191	152.72	44.918
$\frac{5}{8}$	197.68	58.141	155.26	45.664
$\frac{11}{16}$	200.93	59.098	157.81	46.415
$\frac{3}{4}$	204.21	60.063	160.39	47.173
$\frac{13}{16}$	207.52	61.035	162.99	47.937
$\frac{7}{8}$	210.85	62.016	165.60	48.707
$\frac{15}{16}$	214.21	63.004	168.24	49.483
8	217.60	64.000	170.90	50.265

[a] One cubic inch of rolled steel is assumed to weigh 0.2833 lb.

Table 85 Dimensions of Ferrous Pipe

Nominal Pipe Size (in.)	Outside Diameter (in.)	Schedule No.	Wall Thickness (in.)	Inside Diameter (in.)	Cross-Sectional Area		Circumference, ft, or surface, ft^2 / ft of Length		Capacity at 1 ft/sec Velocity		Weight of Plain-End Pipe (lb/ft)
					Metal ($in.^2$)	Flow (ft^2)	Outside	Inside	U.S. gal/ min	lb/hr water	
$\frac{1}{8}$	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
$\frac{1}{4}$	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
$\frac{3}{8}$	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
$\frac{1}{2}$	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
$\frac{3}{4}$	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
$1\frac{1}{4}$	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

$1\frac{1}{2}$	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
		80SX, 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
$2\frac{1}{2}$	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
$3\frac{1}{2}$	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	19.01
		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

(Continues)

Table 85 (*Continued*)

Nominal Pipe Size (in.)	Outside Diameter (in.)	Schedule No.	Wall Thickness (in.)	Inside Diameter (in.)	Cross-Sectional Area		Circumference, ft, or surface, ft^2 / ft of Length		Capacity at 1 ft/sec Velocity		Weight of Plain-End Pipe (lb/ft)
					Metal ($in.^2$)	Flow (ft^2)	Outside	Inside	U.S. gal/min	lb/hr water	
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	7.260	0.3553	2.258	2.113	159.4	79,700	24.70
		40ST, 40S	0.322	7.981	8.396	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
10	10.75	5S	0.134	10.842	4.47	0.5993	2.814	2.744	269.0	134,500	15.23
		10S	0.165	10.420	5.49	0.5922	2.814	2.728	265.8	132,900	18.70
		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	223.4	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	22.22
		10S	0.180	12.390	7.11	0.8373	3.338	3.24	375.8	187,900	24.20
		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	53.56
		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	73.22
		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	22.76
		10S	0.188	13.624	8.16	1.0125	3.665	3.57	454	227,000	27.70
		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	189.12
16	16	5S	0.165	15.670	8.18	1.3393	4.189	4.10	601	300,500	27.87
		10S	0.188	15.624	9.34	1.3314	4.189	4.09	598	299,000	31.62
		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

(*Continues*)

Table 85 ***(Continued)***

Nominal Pipe Size (in.)	Outside Diameter (in.)	Schedule No.	Wall Thickness (in.)	Inside Diameter (in.)	Cross-Sectional Area: Metal (in.^{2})	Cross-Sectional Area: Flow (ft^2)	Circumference, ft, or surface, ft^2 / ft of Length: Outside	Circumference, ft, or surface, ft^2 / ft of Length: Inside	Capacity at 1 ft/sec Velocity: U.S. gal/min	Capacity at 1 ft/sec Velocity: lb/hr water	Weight of Plain-End Pipe (lb/ft)
18	18	5S	0.165	17.670	9.25	1.7029	4.712	4.63	74	382,000	31.32
		10S	0.188	17.624	10.52	1.6941	4.712	4.61	760	379,400	35.48
		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	170.75
		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	39.76
		10S	0.218	19.564	13.55	2.0878	5.236	5.12	937	467,500	45.98
		10	0.250	19.500	15.51	2.0740	5.236	5.11	930	465,000	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	55.08
		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	99.08
		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

Schedule Nos. 5S, 10S, and 40S American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME) B.36.19-1985, ''Stainless Steel Pipe.'' ST = standard wall, XS = extra strong wall, XX = double extra strong wall are all taken from ANSI/ASME, B.36.10M-1985, ''Welded and Seamless Wrought-steel Pipe.'' Wrought-iron pipe has slightly thicker walls, approximately 3%, but the same weight per foot, because of lower density. Decimal thicknesses for respective pipe sizes represent their nominal or average wall dimensions. Mill tolerances as high as $12\frac{1}{2}$% are permitted.

Plain-end pipe is produced by a square cut. Pipe is also shipped from the mills threaded, with a threaded coupling on one end, or with the ends beveled for welding, or grooved or sized for patented couplings. Weights per foot for threaded and coupled pipe are slightly greater because of the weight of the coupling, but it is not available larger than 12 in., or lighter than Schedule 30 sizes 8 through 12 in., or Schedule 40 6 in. and smaller.

Source: From *Chemical Engineer's Handbook*, 4th ed., New York, McGraw-Hill, 1963. Used by permission.

Table 86 Properties and Dimensions of Steel Pipe[a]

Dimensions							Couplings			Properties		
				Weight per Foot (lb)								
Nominal Diameter (in.)	Outside Diameter (in.)	Inside Diameter (in.)	Thickness (in.)	Plain Ends	Thread and Coupling	Threads per Inch	Outside Diameter (in.)	Length (in.)	Weight (lb)	*I* (in.^{4})	*A* (in.^{2})	*k* (in.)
					Schedule 40ST							
$\frac{1}{8}$	0.405	0.269	0.068	0.24	0.25	27	0.562	$\frac{7}{8}$	0.03	0.001	0.072	0.12
$\frac{1}{4}$	0.540	0.364	0.088	0.42	0.43	18	0.685	1	0.04	0.003	0.125	0.16
$\frac{3}{8}$	0.675	0.493	0.091	0.57	0.57	18	0.848	$1\frac{1}{8}$	0.07	0.007	0.167	0.21
$\frac{1}{2}$	0.840	0.622	0.109	0.85	0.85	14	1.024	$1\frac{3}{8}$	0.12	0.017	0.250	0.26
$\frac{3}{4}$	1.050	0.824	0.113	1.13	1.13	14	1.281	$1\frac{5}{8}$	0.21	0.037	0.333	0.33
1	1.315	1.049	0.133	1.68	1.68	$11\frac{1}{2}$	1.576	$1\frac{7}{8}$	0.35	0.087	0.494	0.42
$1\frac{1}{4}$	1.660	1.380	0.140	2.27	2.28	$11\frac{1}{2}$	1.950	$2\frac{1}{8}$	0.55	0.195	0.669	0.54
$1\frac{1}{2}$	1.900	1.610	0.145	2.72	2.73	$11\frac{1}{2}$	2.218	$2\frac{3}{8}$	0.76	0.310	0.799	0.62
2	2.375	2.067	0.154	3.65	3.68	$11\frac{1}{2}$	2.760	$2\frac{5}{8}$	1.23	0.666	1.075	0.79
$2\frac{1}{2}$	2.875	2.469	0.203	5.79	5.82	8	3.276	$2\frac{7}{8}$	1.76	1.530	1.704	0.95
3	3.500	3.068	0.216	7.58	7.62	8	3.948	$3\frac{1}{8}$	2.55	3.017	2.228	1.16
$3\frac{1}{2}$	4.000	3.548	0.226	9.11	9.20	8	4.591	$3\frac{5}{8}$	4.33	4.788	2.680	1.34
4	4.500	4.026	0.237	10.79	10.89	8	5.091	$3\frac{5}{8}$	5.41	7.233	3.174	1.51
5	5.563	5.047	0.258	14.62	14.81	8	6.296	$4\frac{1}{8}$	9.16	15.16	4.300	1.88
6	6.625	6.065	0.280	18.97	19.19	8	7.358	$4\frac{1}{8}$	10.82	28.14	5.581	2.25
8	8.625	8.071	0.277	24.70	25.00	8	9.420	$4\frac{5}{8}$	15.84	63.35	7.265	2.95
8	8.625	7.981	0.322	28.55	28.81	8	9.420	$4\frac{5}{8}$	15.84	72.49	8.399	2.94
10	10.750	10.192	0.279	31.20	32.00	8	11.721	$6\frac{1}{8}$	33.92	125.4	9.178	3.70
10	10.750	10.136	0.307	34.24	35.00	8	11.721	$6\frac{1}{8}$	33.92	137.4	10.07	3.69
10	10.750	10.020	0.365	40.48	41.13	8	11.721	$6\frac{1}{8}$	33.92	160.7	11.91	3.67
12	12.750	12.090	0.330	43.77	45.00	8	13.958	$6\frac{1}{8}$	48.27	248.5	12.88	4.39
12	12.750	12.000	0.375	49.56	50.71	8	13.958	$6\frac{1}{8}$	48.27	279.3	14.38	4.38
					Schedule 80XS							
$\frac{1}{8}$	0.405	0.215	0.095	0.31	0.32	27	0.582	$1\frac{1}{8}$	0.05	0.001	0.093	0.12
$\frac{1}{4}$	0.540	0.302	0.119	0.54	0.54	18	0.724	$1\frac{3}{8}$	0.07	0.004	0.157	0.16
$\frac{3}{8}$	0.675	0.423	0.126	0.74	0.75	18	0.898	$1\frac{5}{8}$	0.13	0.009	0.217	0.20
$\frac{1}{2}$	0.840	0.546	0.147	1.09	1.10	14	1.085	$1\frac{7}{8}$	0.22	0.020	0.320	0.25
$\frac{3}{4}$	1.050	0.742	0.154	1.47	1.49	14	1.316	$2\frac{1}{8}$	0.33	0.045	0.433	0.32
1	1.315	0.957	0.179	2.17	2.20	$11\frac{1}{2}$	1.575	$2\frac{3}{8}$	0.47	0.106	0.639	0.41
$1\frac{1}{4}$	1.660	1.278	0.191	3.00	3.05	$11\frac{1}{2}$	2.054	$2\frac{7}{8}$	1.04	0.242	0.881	0.52
$1\frac{1}{2}$	1.900	1.500	0.200	3.63	3.69	$11\frac{1}{2}$	2.294	$2\frac{7}{8}$	1.17	0.391	1.068	0.61
2	2.375	1.939	0.218	5.02	5.13	$11\frac{1}{2}$	2.870	$3\frac{5}{8}$	2.17	0.868	1.477	0.77
$2\frac{1}{2}$	2.875	2.323	0.276	7.66	7.83	8	3.389	$4\frac{1}{8}$	3.43	1.924	2.254	0.92
3	3.500	2.900	0.300	10.25	10.46	8	4.014	$4\frac{1}{8}$	4.13	3.894	3.016	1.14
$3\frac{1}{2}$	4.000	3.364	0.318	12.51	12.82	8	4.628	$4\frac{5}{8}$	6.29	6.280	3.678	1.31
4	4.500	3.826	0.337	14.98	15.39	8	5.233	$4\frac{5}{8}$	8.16	9.610	4.407	1.48
5	5.563	4.813	0.375	20.78	21.42	8	6.420	$5\frac{1}{8}$	12.87	20.67	6.112	1.84
6	6.625	5.761	0.432	28.57	29.33	8	7.482	$5\frac{1}{8}$	15.18	40.49	8.405	2.20
8	8.625	7.625	0.500	43.39	44.72	8	9.596	$6\frac{1}{8}$	26.63	105.7	12.76	2.88
10	10.750	9.750	0.500	54.74	56.94	8	11.958	$6\frac{5}{8}$	44.16	211.9	16.10	3.63
12	12.750	11.750	0.500	65.42	68.02	8	13.958	$6\frac{5}{8}$	51.99	361.5	19.24	4.34

Table 86 (*Continued*)

Dimensions							Couplings			Properties		
				Weight per Foot (lb)								
Nominal Diameter (in.)	Outside Diameter (in.)	Inside Diameter (in.)	Thickness (in.)	Plain Ends	Thread and Coupling	Threads per Inch	Outside Diameter (in.)	Length (in.)	Weight (lb)	I (in.^{4})	A (in.^{2})	k (in.)
						Schedule XX						
$\frac{1}{2}$	0.840	0.252	0.294	1.71	1.73	14	1.085	$1\frac{7}{8}$	0.22	0.024	0.504	0.22
$\frac{3}{4}$	1.050	0.434	0.308	2.44	2.46	14	1.316	$2\frac{1}{8}$	0.33	0.058	0.718	0.28
1	1.315	0.599	0.358	3.66	3.68	$11\frac{1}{2}$	1.575	$2\frac{3}{8}$	0.47	0.140	1.076	0.36
$1\frac{1}{4}$	1.660	0.896	0.382	5.21	5.27	$11\frac{1}{2}$	2.054	$2\frac{7}{8}$	1.04	0.341	1.534	0.47
$1\frac{1}{2}$	1.900	1.100	0.400	6.41	6.47	$11\frac{1}{2}$	2.294	$2\frac{7}{8}$	1.17	0.568	1.885	0.55
2	2.375	1.503	0.436	9.03	9.14	$11\frac{1}{2}$	2.870	$3\frac{5}{8}$	2.17	1.311	2.656	0.70
$2\frac{1}{2}$	2.875	1.771	0.552	13.70	13.87	8	3.389	$4\frac{1}{8}$	3.43	2.871	4.028	0.84
3	3.500	2.300	0.600	18.58	18.79	8	4.014	$4\frac{1}{8}$	4.13	5.992	5.466	1.05
$3\frac{1}{2}$	4.000	2.728	0.636	22.85	23.16	8	4.628	$4\frac{5}{8}$	6.29	9.848	6.721	1.21
4	4.500	3.152	0.674	27.54	27.95	8	5.233	$4\frac{5}{8}$	8.16	15.28	8.101	1.37
5	5.563	4.063	0.750	38.55	39.20	8	6.420	$5\frac{1}{8}$	12.87	33.64	11.34	1.72
6	6.625	4.897	0.864	53.16	53.92	8	7.482	$5\frac{1}{8}$	15.18	66.33	15.64	2.06
8	8.625	6.875	0.875	72.42	73.76	8	9.596	$6\frac{1}{8}$	26.63	162.0	21.30	2.76
						Large Outside Diameter Pipe						

Pipe 14 in. and larger is sold by actual outside step diameter and thickness.

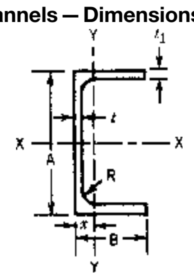
Sizes 14, 15, and 16 in. are available regularly in thicknesses varying by $\frac{1}{16}$ in. from $\frac{1}{4}$ to 1 in., inclusive.

All pipe is furnished random length unless otherwise ordered, viz: 12–22 ft with privilege of furnishing 5 % in 6–12-ft lengths. Pipe railing is most economically detailed with slip joints and random lengths between couplings.

[a] *Steel Construction*, 1980, A.I.S.C.

6.6 Standard Structural Shapes — Aluminum*

Table 87 Aluminum Association Standard Channels — Dimensions, Areas, Weights, and Section Properties[a]



Size							Section Properties[d]						
Depth	Width			Flange Thickness	Web Thickness	Fillet Radius	Axis X–X			Axis Y–Y			
A (in.)	B (in.)	Area[b] (in.^{2})	Weight[c] (lb/ft)	t_1 (in.)	t (in.)	R (in.)	I (in.^{4})	S (in.^{3})	r (in.)	I (in.^{4})	S (in.^{3})	r (in.)	x (in.)
2.00	1.00	0.491	0.557	0.13	0.13	0.10	0.288	0.288	0.766	0.045	0.064	0.303	0.298
2.00	1.25	0.911	1.071	0.26	0.17	0.15	0.546	0.546	0.774	0.139	0.178	0.391	0.471
3.00	1.50	0.965	1.135	0.20	0.13	0.25	1.41	0.94	1.21	0.22	0.22	0.47	0.49
3.00	1.75	1.358	1.597	0.26	0.17	0.25	1.97	1.31	1.20	0.42	0.37	0.55	0.62
4.00	2.00	1.478	1.738	0.23	0.15	0.25	3.91	1.95	1.63	0.60	0.45	0.64	0.65
4.00	2.25	1.982	2.331	0.29	0.19	0.25	5.21	2.60	1.62	1.02	0.69	0.72	0.78
5.00	2.25	1.881	2.212	0.26	0.15	0.30	7.88	3.15	2.05	0.98	0.64	0.72	0.73
5.00	2.75	2.627	3.089	0.32	0.19	0.30	11.14	4.45	2.06	2.05	1.14	0.88	0.95

(*Continues*)

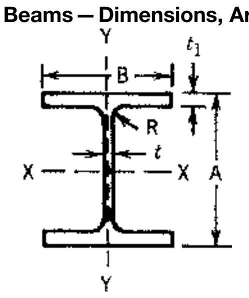
*Tables 87–101 are from *Aluminum Standards and Data.* Copyright © 1984 The Aluminum Association.

Table 87 (*Continued*)

Size							Section Properties[d]						
Depth	Width			Flange Thickness	Web Thickness	Fillet Radius	Axis $X-X$			Axis $Y-Y$			
A (in.)	B (in.)	Area[b] (in.^{2})	Weight[c] (lb/ft)	t_1 (in.)	t (in.)	R (in.)	I (in.^{4})	S (in.^{3})	r (in.)	I (in.^{4})	S (in.^{3})	r (in.)	x (in.)
6.00	2.50	2.410	2.834	0.29	0.17	0.30	14.35	4.78	2.44	1.53	0.90	0.80	0.79
6.00	3.25	3.427	4.030	0.35	0.21	0.30	21.04	7.01	2.48	3.76	1.76	1.05	1.12
7.00	2.75	2.725	3.205	0.29	0.17	0.30	22.09	6.31	2.85	2.10	1.10	0.88	0.84
7.00	3.50	4.009	4.715	0.38	0.21	0.30	33.79	9.65	2.90	5.13	2.23	1.13	1.20
8.00	3.00	3.526	4.147	0.35	0.19	0.30	37.40	9.35	3.26	3.25	1.57	0.96	0.93
8.00	3.75	4.923	5.789	0.41	0.25	0.35	52.69	13.17	3.27	7.13	2.82	1.20	1.22
9.00	3.25	4.237	4.983	0.35	0.23	0.35	54.41	12.09	3.58	4.40	1.89	1.02	0.93
9.00	4.00	5.927	6.970	0.44	0.29	0.35	78.31	17.40	3.63	9.61	3.49	1.27	1.25
10.00	3.50	5.218	6.136	0.41	0.25	0.35	83.22	16.64	3.99	6.33	2.56	1.10	1.02
10.00	4.25	7.109	8.360	0.50	0.31	0.40	116.15	23.23	4.04	13.02	4.47	1.35	1.34
12.00	4.00	7.036	8.274	0.47	0.29	0.40	159.76	26.63	4.77	11.03	3.86	1.25	1.14
12.00	5.00	10.053	11.822	0.62	0.35	0.45	239.69	39.95	4.88	25.74	7.60	1.60	1.61

[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098 lb/in.^{3}, which is the density of alloy 6061.
[d] I = moment of inertia; S = section modulus; r = radius of gyration.

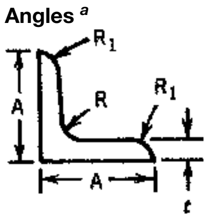
Table 88 Aluminum Association Standard I Beams—Dimensions, Areas, Weights, and Section Properties[a]



Size							Section Properties[d]					
Depth	Width			Flange Thickness	Web Thickness	Fillet Radius	Axis $X-X$			Axis $Y-Y$		
A (in.)	B (in.)	Area[b] (in.^{2})	Weight[c] (lb/ft)	t_1 (in.)	t (in.)	R (in.)	I (in.^{4})	S (in.^{3})	r (in.)	I (in.^{4})	S (in.^{3})	r (in.)
3.00	2.50	1.392	1.637	0.20	0.13	0.25	2.24	1.49	1.27	0.52	0.42	0.61
3.00	2.50	1.726	2.030	0.26	0.15	0.25	2.71	1.81	1.25	0.68	0.54	0.63
4.00	3.00	1.965	2.311	0.23	0.15	0.25	5.62	2.81	1.69	1.04	0.69	0.73
4.00	3.00	2.375	2.793	0.29	0.17	0.25	6.71	3.36	1.68	1.31	0.87	0.74
5.00	3.50	3.146	3.700	0.32	0.19	0.30	13.94	5.58	2.11	2.29	1.31	0.85
6.00	4.00	3.427	4.030	0.29	0.19	0.30	21.99	7.33	2.53	3.10	1.55	0.95
6.00	4.00	3.990	4.692	0.35	0.21	0.30	25.50	8.50	2.53	3.74	1.87	0.97
7.00	4.50	4.932	5.800	0.38	0.23	0.30	42.89	12.25	2.95	5.78	2.57	1.08
8.00	5.00	5.256	6.181	0.35	0.23	0.30	59.69	14.92	3.37	7.30	2.92	1.18
8.00	5.00	5.972	7.023	0.41	0.25	0.30	67.78	16.94	3.37	8.55	3.42	1.20
9.00	5.50	7.110	8.361	0.44	0.27	0.30	102.02	22.67	3.79	12.22	4.44	1.31
10.00	6.00	7.352	8.646	0.41	0.25	0.40	132.09	26.42	4.24	14.78	4.93	1.42
10.00	6.00	8.747	10.286	0.50	0.29	0.40	155.79	31.16	4.22	18.03	6.01	1.44
12.00	7.00	9.925	11.672	0.47	0.29	0.40	255.57	42.60	5.07	26.90	7.69	1.65
12.00	7.00	12.153	14.292	0.62	0.31	0.40	317.33	52.89	5.11	35.48	10.14	1.71

[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098 lb/in.^{3}, which is the density of alloy 6061.
[d] I = moment of inertia; S = section modulus; r = radius of gyration.

Table 89 Standard Structural Shapes — Equal Angles [a]



A	t	R	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
$\frac{3}{4}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{32}$	0.171	0.201
$\frac{3}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	$\frac{3}{32}$	0.246	0.289
1	$\frac{3}{32}$	$\frac{1}{8}$	$\frac{3}{32}$	0.179	0.211
1	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{3}{32}$	0.234	0.275
1	$\frac{3}{16}$	$\frac{1}{8}$	$\frac{3}{32}$	0.340	0.400
1	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{32}$	0.437	0.514
$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	0.292	0.343
$1\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	0.434	0.510
$1\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	0.558	0.656
$1\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	0.360	0.423
$1\frac{1}{2}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	0.529	0.619
$1\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	0.688	0.809
$1\frac{3}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	0.423	0.497
$1\frac{3}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	0.622	0.731
$1\frac{3}{4}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	0.813	0.956
$1\frac{3}{4}$	$\frac{5}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	0.996	1.171
2	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	0.491	0.577
2	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{8}$	0.723	0.850
2	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	0.944	1.110
2	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{1}{8}$	1.160	1.364
2	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	1.366	1.606
$2\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	0.616	0.724
$2\frac{1}{2}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{8}$	0.910	1.070
$2\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	1.194	1.404
$2\frac{1}{2}$	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{1}{8}$	1.470	1.729
$2\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	1.714	2.047
3	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{1}{4}$	1.084	1.275
3	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{4}$	1.432	1.684
3	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{1}{4}$	1.770	2.082
3	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	2.104	2.474
3	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{1}{4}$	2.428	2.855
3	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{1}{4}$	2.744	3.227
$3\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	1.691	1.989
$3\frac{1}{2}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	2.093	2.461
$3\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	2.488	2.926
$3\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	3.253	3.826

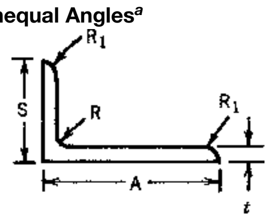
(*Continues*)

Table 89 (*Continued*)

A	*t*	*R*	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
4	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	1.941	2.283
4	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	2.406	2.829
4	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	2.862	3.366
4	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	3.310	3.893
4	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	3.753	4.414
4	$\frac{9}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	4.187	4.924
4	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	4.613	5.425
4	$\frac{11}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	5.032	5.918
4	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	5.441	6.399
5	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	3.603	4.237
5	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{3}{8}$	4.177	4.912
5	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	4.743	5.578
5	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	5.853	6.883
6	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	4.353	5.119
6	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{3}{8}$	5.052	5.941
6	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	5.743	6.754
6	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	7.102	8.352
8	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{8}$	7.773	9.141
8	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{3}{8}$	11.461	13.478
8	1	$\frac{5}{8}$	$\frac{3}{8}$	15.023	17.667

[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098 lb/in.^{3}, which is the density of alloy 6061.

Table 90 Standard Structural Shapes — Unequal Angles[a]



A	*B*	*t*	*R*	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
$1\frac{1}{4}$	$\frac{3}{4}$	$\frac{3}{32}$	$\frac{3}{32}$	$\frac{3}{64}$	0.180	0.212
$1\frac{1}{4}$	1	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{16}$	0.267	0.314
$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{16}$	0.267	0.314
$1\frac{1}{2}$	$\frac{3}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	$\frac{3}{32}$	0.386	0.454
$1\frac{1}{2}$	1	$\frac{5}{32}$	$\frac{5}{32}$	$\frac{5}{64}$	0.368	0.433
$1\frac{1}{2}$	1	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	0.563	0.662
$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	0.329	0.387
$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	0.481	0.566
$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	0.624	0.734
$1\frac{3}{4}$	$1\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	0.358	0.421

Table 90 (*Continued*)

A	*B*	*t*	*R*	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
$1\frac{3}{4}$	$1\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	0.528	0.621
$1\frac{3}{4}$	$1\frac{1}{4}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	0.688	0.809
2	$1\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	0.422	0.496
2	$1\frac{1}{2}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	0.622	0.731
2	$1\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{8}$	0.813	0.956
2	$1\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{1}{8}$	1.172	1.378
$2\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{8}$	0.723	0.850
$2\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	0.944	1.110
$2\frac{1}{2}$	$1\frac{1}{2}$	$\frac{5}{16}$	$\frac{3}{16}$	$\frac{1}{8}$	1.152	1.355
$2\frac{1}{2}$	2	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	0.554	0.652
$2\frac{1}{2}$	2	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{8}$	0.817	0.961
$2\frac{1}{2}$	2	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{8}$	1.069	1.257
$2\frac{1}{2}$	2	$\frac{5}{16}$	$\frac{1}{4}$	$\frac{1}{8}$	1.314	1.545
$2\frac{1}{2}$	2	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	1.554	1.828
3	2	$\frac{3}{16}$	$\frac{5}{16}$	$\frac{3}{16}$	0.911	1.071
3	2	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{16}$	1.193	1.403
3	2	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{3}{16}$	1.471	1.730
3	2	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{3}{16}$	1.740	2.046
3	2	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{3}{16}$	2.001	2.353
3	$2\frac{1}{2}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{4}$	1.307	1.537
3	$2\frac{1}{2}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{1}{4}$	1.614	1.898
3	$2\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	1.916	2.253
$3\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{1}{4}$	1.432	1.684
$3\frac{1}{2}$	$2\frac{1}{2}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{1}{4}$	1.770	2.082
$3\frac{1}{2}$	$2\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	$\frac{1}{4}$	2.104	2.474
$3\frac{1}{2}$	$2\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{1}{4}$	2.744	3.227
$3\frac{1}{2}$	3	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	1.566	1.842
$3\frac{1}{2}$	3	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	1.937	2.278
$3\frac{1}{2}$	3	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	2.300	2.705
$3\frac{1}{2}$	3	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	3.003	3.532
4	3	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{4}$	1.691	1.988
4	3	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	2.091	2.459
4	3	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	2.488	2.926
4	3	$\frac{7}{16}$	$\frac{3}{8}$	$\frac{1}{4}$	2.874	3.380
4	3	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{4}$	3.253	3.826
4	3	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	3.988	4.690
4	$3\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{5}{16}$	2.660	3.128
4	$3\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	3.488	4.102
5	3	$\frac{3}{8}$	$\frac{3}{8}$	$\frac{5}{16}$	2.848	3.349
5	3	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{5}{16}$	3.738	4.396
5	$3\frac{1}{2}$	$\frac{5}{16}$	$\frac{7}{16}$	$\frac{5}{16}$	2.558	3.008
5	$3\frac{1}{2}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{5}{16}$	3.046	3.582
5	$3\frac{1}{2}$	$\frac{7}{16}$	$\frac{7}{16}$	$\frac{5}{16}$	3.527	4.148

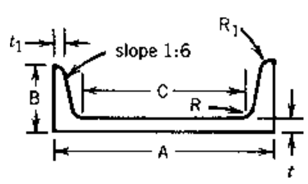
(*Continues*)

Table 90 (*Continued*)

A	*B*	*t*	*R*	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
5	$3\frac{1}{2}$	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{5}{16}$	4.000	4.704
5	$3\frac{1}{2}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{5}{16}$	4.921	5.787
6	$3\frac{1}{2}$	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{5}{16}$	2.878	3.385
6	$3\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{16}$	3.433	4.037
6	$3\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{16}$	4.512	5.306
6	4	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	3.603	4.237
6	4	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{3}{8}$	4.179	4.915
6	4	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{3}{8}$	4.743	5.578
6	4	$\frac{9}{16}$	$\frac{1}{2}$	$\frac{3}{8}$	5.298	6.230
6	4	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	5.853	6.883
6	4	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{8}$	6.931	8.151
8	6	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{5}{16}$	8.371	9.844
8	6	$\frac{11}{16}$	$\frac{1}{2}$	$\frac{3}{8}$	9.152	10.763
8	6	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{3}{8}$	9.931	11.679

[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098lb/in.^{3}, which is the density of alloy 6061.

Table 91 Channels, American Standard[a]



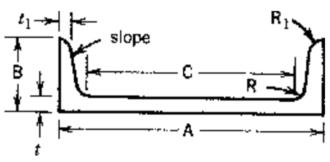
A	*B*	*C*	*t*	t_1	*R*	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
3	1.410	$1\frac{3}{4}$	0.170	0.170	0.270	0.100	1.205	1.417
3	1.498	$1\frac{3}{4}$	0.258	0.170	0.270	0.100	1.470	1.729
3	1.596	$1\frac{3}{4}$	0.356	0.170	0.270	0.100	1.764	2.074
4	1.580	$2\frac{3}{4}$	0.180	0.180	0.280	0.110	1.570	1.846
4	1.647	$2\frac{3}{4}$	0.247	0.180	0.280	0.110	1.838	2.161
4	1.720	$2\frac{3}{4}$	0.320	0.180	0.280	0.110	2.129	2.504
5	1.750	$3\frac{3}{4}$	0.190	0.190	0.290	0.110	1.969	2.316
5	1.885	$3\frac{3}{4}$	0.325	0.190	0.290	0.110	2.643	3.108
5	2.032	$3\frac{3}{4}$	0.472	0.190	0.290	0.110	3.380	3.975
6	1.920	$4\frac{1}{2}$	0.200	0.200	0.300	0.120	2.403	2.826
6	1.945	$4\frac{1}{2}$	0.225	0.200	0.300	0.120	2.553	3.002
6	2.034	$4\frac{1}{2}$	0.314	0.200	0.300	0.120	3.088	3.631
6	2.157	$4\frac{1}{2}$	0.437	0.200	0.300	0.120	3.825	4.498
7	2.110	$5\frac{1}{2}$	0.230	0.210	0.310	0.130	3.011	3.541
7	2.194	$5\frac{1}{2}$	0.314	0.210	0.310	0.130	3.599	4.232
7	2.299	$5\frac{1}{2}$	0.419	0.210	0.310	0.130	4.334	5.097
8	2.290	$6\frac{1}{4}$	0.250	0.220	0.320	0.130	3.616	4.252
8	2.343	$6\frac{1}{4}$	0.303	0.220	0.320	0.130	4.040	4.751
8	2.435	$6\frac{1}{4}$	0.395	0.220	0.320	0.130	4.776	5.617
8	2.527	$6\frac{1}{4}$	0.487	0.220	0.320	0.130	5.514	6.484

Table 91 (*Continued*)

A	*B*	*C*	*t*	t_1	*R*	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
9	2.430	$7\frac{1}{4}$	0.230	0.230	0.330	0.140	3.915	4.604
9	2.648	$7\frac{1}{4}$	0.448	0.230	0.330	0.140	5.877	6.911
10	2.600	$8\frac{1}{4}$	0.240	0.240	0.340	0.140	4.488	5.278
10	2.886	$8\frac{1}{4}$	0.526	0.240	0.340	0.140	7.348	8.641
12	2.960	10	0.300	0.280	0.380	0.170	6.302	7.411
12	3.047	10	0.387	0.280	0.380	0.170	7.346	8.639
12	3.170	10	0.510	0.280	0.380	0.170	8.822	10.374
15	3.400	$12\frac{3}{8}$	0.400	0.400	0.500	0.240	9.956	11.708
15	3.716	$12\frac{3}{8}$	0.716	0.400	0.500	0.240	14.696	17.282

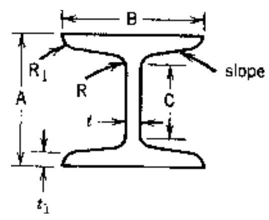
[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098 lb/in.^{3}, which is the density of alloy 6061.

Table 92 Channels, Shipbuilding, and Carbuilding[a]



A	*B*	*C*	*t*	t_1	*R*	R_1	Slope	Area[b] (in.^{2})	Weight per Foot[c] (lb)
3	2	$1\frac{3}{4}$	0.250	0.250	0.250	0	12:12.1	1.900	2.234
3	2	$1\frac{7}{8}$	0.375	0.375	0.188	0.375	0	2.298	2.702
4	$2\frac{1}{2}$	$2\frac{3}{8}$	0.318	0.313	0.375	0.125	1:34.9	2.825	3.322
5	$2\frac{7}{8}$	3	0.438	0.438	0.250	0.094	1:9.8	4.950	5.821
6	3	$4\frac{1}{2}$	0.500	0.375	0.375	0.250	0	4.909	5.773
6	$3\frac{1}{2}$	4	0.375	0.412	0.480	0.420	1:49.6	5.044	5.932
8	3	$5\frac{3}{4}$	0.380	0.380	0.550	0.220	1:14.43	5.600	6.586
8	$3\frac{1}{2}$	$5\frac{3}{4}$	0.425	0.471	0.525	0.375	1:28.5	6.682	7.858
10	$3\frac{1}{2}$	$7\frac{1}{2}$	0.375	0.375	0.625	0.188	1:9	7.298	8.581
10	$3\frac{9}{16}$	$7\frac{1}{2}$	0.438	0.375	0.625	0.188	1:9	7.928	9.323
10	$3\frac{5}{8}$	$7\frac{1}{2}$	0.500	0.375	0.625	0.188	1:9	8.548	10.052

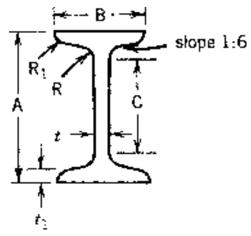
Table 93 H Beams[a]



A	*B*	*C*	*t*	t_1	*R*	R_1	Slope	Area[b] (in.^{2})	Weight per Foot[c] (lb)
4	4	$2\frac{3}{8}$	0.313	0.290	0.313	0.145	1:11.3	4.046	4.758
5	5	$3\frac{3}{8}$	0.313	0.330	0.313	0.165	1:13.6	5.522	6.494
6	5.938	$4\frac{3}{8}$	0.250	0.360	0.313	0.180	1:15.6	6.678	7.853
8	7.938	$6\frac{1}{4}$	0.313	0.358	0.313	0.179	1:18.9	9.554	11.263
8	8.125	$6\frac{1}{4}$	0.500	0.358	0.313	0.179	1:18.9	11.050	12.995

[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098 lb/in.^{3}, which is the density of alloy 6061.

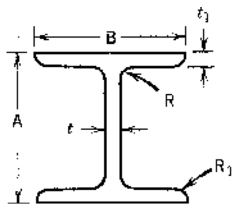
Table 94 I Beams[a]



A	B	C	t	t_1	R	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
3	2.330	$1\frac{3}{4}$	0.170	0.170	0.270	0.100	1.669	1.963
3	2.509	$1\frac{3}{4}$	0.349	0.170	0.270	0.100	2.203	2.591
4	2.660	$2\frac{3}{4}$	0.190	0.190	0.290	0.110	2.249	2.644
4	2.796	$2\frac{3}{4}$	0.326	0.190	0.290	0.110	2.792	3.283
5	3	$3\frac{1}{2}$	0.210	0.210	0.310	0.130	2.917	3.430
5	3.284	$3\frac{1}{2}$	0.494	0.210	0.310	0.130	4.337	5.100
6	3.330	$4\frac{1}{2}$	0.230	0.230	0.330	0.140	3.658	4.302
6	3.443	$4\frac{1}{2}$	0.343	0.230	0.330	0.140	4.336	5.099
7	3.755	$5\frac{1}{4}$	0.345	0.250	0.350	0.150	5.147	6.053
8	4	$6\frac{1}{4}$	0.270	0.270	0.370	0.160	5.398	6.348
8	4.262	$6\frac{1}{4}$	0.532	0.270	0.370	0.160	7.494	8.813
10	4.660	8	0.310	0.310	0.410	0.190	7.452	8.764
12	5	$9\frac{3}{4}$	0.350	0.350	0.450	0.210	9.349	10.994

[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098 lb/in.^{3}, which is the density of alloy 6061.

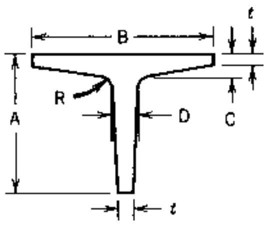
Table 95 Wide-Flange Beams[a]



A	B	t	t_1	R	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
6.000	4.000	0.230	0.279	0.250	—	3.538	4.161
6.000	6.000	0.240	0.269	0.250	—	4.593	5.401
8.000	5.250	0.230	0.308	0.320	—	5.020	5.904
8.000	6.500	0.245	0.398	0.400	—	7.076	8.321
8.000	8.000	0.288	0.433	0.400	—	9.120	10.725
9.750	7.964	0.292	0.433	0.500	—	9.706	11.414
9.900	5.750	0.240	0.340	0.312	0.031	6.205	7.297
11.940	8.000	0.294	0.516	0.600	—	11.772	13.844
12.060	10.000	0.345	0.576	0.600	—	15.593	18.337

[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098 lb/in.^{3}, which is the density of alloy 6061.

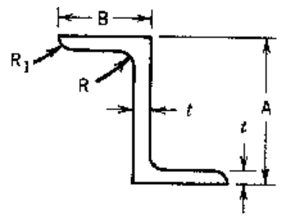
Table 96 Tees[a]



A	B	C	D	t	R	Area[b] (in.^{2})	Weight per Foot[c] (lb)
2	2	0.312	0.312	0.250	0.250	1.071	1.259
$2\frac{1}{4}$	$2\frac{1}{4}$	0.312	0.312	0.250	0.250	1.208	1.421
$2\frac{1}{2}$	$2\frac{1}{2}$	0.375	0.375	0.312	0.250	1.626	1.912
3	3	0.438	0.438	0.375	0.312	2.310	2.717
4	4	0.438	0.438	0.375	0.500	3.183	3.743

[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098 lb/in.^{3}, which is the density of alloy 6061.

Table 97 Zees[a]



A	B	t	R	R_1	Area[b] (in.^{2})	Weight per Foot[c] (lb)
3	$2\frac{11}{16}$	0.250	0.312	0.250	1.984	2.333
3	$2\frac{11}{16}$	0.375	0.312	0.250	2.875	3.381
4	$3\frac{1}{16}$	0.250	0.312	0.250	2.422	2.848
$4\frac{1}{16}$	$3\frac{1}{8}$	0.312	0.312	0.250	3.040	3.575
$4\frac{1}{4}$	$3\frac{3}{16}$	0.375	0.312	0.250	3.672	4.318
5	$3\frac{1}{4}$	0.500	0.312	0.250	5.265	6.192
$5\frac{1}{16}$	$3\frac{5}{16}$	0.375	0.312	0.250	4.093	4.813

[a] Users are encouraged to ascertain current availability of particular structural shapes through inquiries to their suppliers.
[b] Areas listed are based on nominal dimensions.
[c] Weights per foot are based on nominal dimensions and a density of 0.098 lb/in.^{3}, which is the density of alloy 6061.

Table 98 Aluminum Pipe — Diameters, Wall Thicknesses, and Weights

Nominal Pipe Size[a] (in.)	Schedule Number[a]	Outside Diameter (in.)			Inside Diameter (in.)	Wall Thickness (in.)			Weight per Foot (lb)	
		Nom[a]	Min[b,c]	Max[b,c]	Nom	Nom[a]	Min[b]	Max[b]	Nom[d]	Min[b,d]
$\frac{1}{8}$	40	0.405	0.374	0.420	0.269	0.068	0.060	—	0.085	0.091
	80	0.405	0.374	0.420	0.215	0.095	0.083	—	0.109	0.118
$\frac{1}{4}$	40	0.540	0.509	0.555	0.364	0.088	0.077	—	0.147	0.159
	80	0.540	0.509	0.555	0.302	0.119	0.104	—	0.185	0.200
$\frac{3}{8}$	40	0.675	0.644	0.690	0.493	0.091	0.080	—	0.196	0.212
	80	0.675	0.644	0.690	0.493	0.091	0.080	—	0.196	0.212
	5	0.840	0.809	0.855	0.710	0.065	0.053	0.077	0.186	—
	10	0.840	0.809	0.855	0.674	0.083	0.071	0.095	0.232	—
$\frac{1}{2}$	40	0.840	0.809	0.855	0.622	0.109	0.095	—	0.294	0.318
	80	0.840	0.809	0.855	0.546	0.147	0.129	—	0.376	0.406
	160	0.840	0.809	0.855	0.464	0.188	0.164	—	0.453	0.489
	5	1.050	1.019	1.065	0.920	0.065	0.053	0.077	0.237	—
	10	1.050	1.019	1.065	0.884	0.083	0.071	0.095	0.297	—
$\frac{3}{4}$	40	1.050	1.019	1.065	0.824	0.113	0.099	—	0.391	0.422
	80	1.050	1.019	1.065	0.742	0.154	0.135	—	0.510	0.551
	160	1.050	1.019	1.065	0.612	0.219	0.192	—	0.672	0.726
	5	1.315	1.284	1.330	1.185	0.065	0.053	0.077	0.300	—
	10	1.315	1.284	1.330	1.097	0.109	0.095	0.123	0.486	—
1	40	1.315	1.284	1.330	1.049	0.133	0.116	—	0.581	0.627
	80	1.315	1.284	1.330	0.957	0.179	0.157	—	0.751	0.811
	160	1.315	1.284	1.330	0.815	0.250	0.219	—	0.984	1.062
	5	1.660	1.629	1.675	1.530	0.065	0.053	0.077	0.383	—
	10	1.660	1.629	1.675	1.442	0.109	0.095	0.123	0.625	—
$1\frac{1}{4}$	40	1.660	1.629	1.675	1.380	0.140	0.122	—	0.786	0.849
	80	1.660	1.629	1.675	1.278	0.191	0.167	—	1.037	1.120
	160	1.660	1.629	1.675	1.160	0.250	0.219	—	1.302	1.407
	5	1.900	1.869	1.915	1.770	0.065	0.053	0.077	0.441	—
	10	1.900	1.869	1.915	1.682	0.109	0.095	0.123	0.721	—
$1\frac{1}{2}$	40	1.900	1.869	1.915	1.610	0.145	0.127	—	0.940	1.015
	80	1.900	1.869	1.915	1.500	0.200	0.175	—	1.256	1.357
	160	1.900	1.869	1.915	1.338	0.281	0.246	—	1.681	1.815
	5	2.375	2.344	2.406	2.245	0.065	0.053	0.077	0.555	—
	10	2.375	2.344	2.406	2.157	0.109	0.095	0.123	0.913	—
2	40	2.375	2.351	2.399	2.067	0.154	0.135	—	1.264	1.365
	80	2.375	2.351	2.399	1.939	0.218	0.191	—	1.737	1.876
	160	2.375	2.351	2.399	1.687	0.344	0.301	—	2.581	2.788
	5	2.875	2.844	2.906	2.709	0.083	0.071	0.095	0.856	—
	10	2.875	2.844	2.906	2.635	0.120	0.105	0.135	1.221	—
$2\frac{1}{2}$	40	2.875	2.846	2.904	2.469	0.203	0.178	—	2.004	2.164
	80	2.875	2.846	2.904	2.323	0.276	0.242	—	2.650	2.862
	160	2.875	2.846	2.904	2.125	0.375	0.328	—	3.464	3.741
	5	3.500	3.469	3.531	3.334	0.083	0.071	0.095	1.048	—
	10	3.500	3.469	3.531	3.260	0.120	0.105	0.135	1.498	—
3	40	3.500	3.465	3.535	3.068	0.216	0.189	—	2.621	2.830
	80	3.500	3.465	3.535	2.900	0.300	0.262	—	3.547	3.830
	160	3.500	3.465	3.535	2.624	0.438	0.383	—	4.955	5.351
$3\frac{1}{2}$	5	4.000	3.969	4.031	3.834	0.083	0.071	0.095	1.201	—
	10	4.000	3.969	4.031	3.760	0.120	0.105	0.135	1.720	—
	40	4.000	3.960	4.040	3.548	0.226	0.198	—	3.151	3.403
	80	4.000	3.960	4.040	3.364	0.318	0.278	—	4.326	4.672

Table 98 (*Continued*)

Nominal Pipe Size[a] (in.)	Schedule Number[a]	Outside Diameter (in.)			Inside Diameter (in.)	Wall Thickness (in.)			Weight per Foot (lb)	
		Nom[a]	Min[b,c]	Max[b,c]	Nom	Nom[a]	Min[b]	Max[b]	Nom[d]	Min[b,d]
4	5	4.500	4.469	4.531	4.334	0.083	0.071	0.095	1.354	—
	10	4.500	4.469	4.531	4.160	0.120	0.105	0.135	1.942	—
	40	4.500	4.455	4.545	4.026	0.237	0.207	—	3.733	4.031
	80	4.500	4.455	4.545	3.826	0.337	0.295	—	5.183	5.598
	120	4.500	4.455	4.545	3.624	0.438	0.383	—	6.573	7.099
	160	4.500	4.455	4.545	3.438	0.531	0.465	—	7.786	8.409
5	5.563	5.532	5.625	5.345	0.109	0.095	0.123	2.196	—	—
	10	5.563	5.532	5.625	5.295	0.134	0.117	0.151	2.688	—
	40	5.563	5.507	5.619	5.047	0.258	0.226	—	7.057	5.461
	80	5.563	5.507	5.619	4.813	0.375	0.328	—	7.188	7.763
	120	5.563	5.507	5.619	4.563	0.500	0.438	—	9.353	10.10
	160	5.563	5.507	5.619	4.313	0.625	0.547	—	11.40	12.31
6	5	6.625	6.594	6.687	6.407	0.109	0.095	0.123	2.624	—
	10	6.625	6.594	6.687	6.357	0.134	0.117	0.151	3.213	—
	40	6.625	6.559	6.691	6.065	0.280	0.245	—	6.564	7.089
	80	6.625	6.559	6.691	5.761	0.432	0.378	—	9.884	10.67
	120	6.625	6.559	6.691	5.501	0.562	0.492	—	12.59	13.60
	160	6.625	6.559	6.691	5.187	0.719	0.629	—	15.69	16.94
	5	8.625	8.594	8.718	8.407	0.109	0.095	0.123	3.429	—
	10	8.625	8.594	8.718	8.329	0.148	0.130	0.166	4.635	—
	20	8.625	8.539	8.711	8.125	0.250	0.219	—	7.735	8.354
	30	8.625	8.539	8.711	8.071	0.277	0.242	—	8.543	9.227
	40	8.625	8.539	8.711	7.981	0.322	0.282	—	9.878	10.67
8	60	8.625	8.539	8.711	7.813	0.406	0.355	—	12.33	13.31
	80	8.625	8.539	8.711	7.625	0.500	0.438	—	15.01	16.21
	100	8.625	8.539	8.711	7.437	0.594	0.520	—	17.62	19.03
	120	8.625	8.539	8.711	7.187	0.719	0.629	—	21.00	22.68
	140	8.625	8.539	8.711	7.001	0.812	0.710	—	23.44	25.31
	160	8.625	8.539	8.711	6.813	0.906	0.793	—	25.84	27.90
10	5	10.750	10.719	10.843	10.482	0.134	0.117	0.151	5.256	—
	10	10.750	10.719	10.843	10.420	0.165	0.144	0.186	6.453	—
	20	10.750	10.642	10.858	10.250	0.250	0.219	—	9.698	10.47
	30	10.750	10.642	10.858	10.136	0.307	0.269	—	11.84	12.69
	40	10.750	10.642	10.858	10.020	0.365	0.319	—	14.00	15.12
	60	10.750	10.642	10.858	9.750	0.500	0.438	—	18.93	24.07
	80	10.750	10.642	10.858	9.562	0.594	0.520	—	22.29	28.78
	100	10.750	10.642	10.858	9.312	0.719	0.629	—	26.65	28.78
	5	12.750	12.719	12.843	12.438	0.156	0.136	0.176	7.258	—
	10	12.750	12.719	12.843	12.390	0.180	0.158	0.202	8.359	—
	20	12.750	12.622	12.878	12.250	0.250	0.219	—	11.55	12.47
12	30	12.750	12.622	12.878	12.090	0.330	0.289	—	15.14	16.35
	40	12.750	12.622	12.878	11.938	0.406	0.355	—	18.52	20.00
	60	12.750	12.622	12.878	11.626	0.562	0.492	—	25.31	27.33
	80	12.750	12.622	12.878	11.374	0.688	0.602	—	30.66	33.11

[a] In accordance with ANSI Standards B36.10 and B36.19.
[b] Based on standard tolerances for pipe.
[c] For schedules 5 and 10 these values apply to mean outside diameters.
[d] Based on nominal dimensions, plain ends, and a density of 0.098 lb/in.^{3}, the density of 6061 alloy. For alloy 6063 multiply by 0.99, and for alloy 3003 multiply by 1.01.

Table 99 Aluminum Electrical Conduit — Designed Dimensions and Weights

Nominal or Trade Size of Conduit (in.)	Nominal Inside Diameter (in.)	Outside Diameter (in.)	Nominal Wall Thickness (in.)	Length without Coupling (ft and in.)	Minimum Weight of 10 Unit Lengths with Couplings Attached (lb)
$\frac{1}{4}$	0.364	0.540	0.088	9–11$\frac{1}{2}$	13.3
$\frac{3}{8}$	0.493	0.675	0.091	9–11$\frac{1}{2}$	17.8
$\frac{1}{2}$	0.622	0.840	0.109	9–11$\frac{1}{4}$	27.4
$\frac{3}{4}$	0.824	1.050	0.113	9–11$\frac{1}{4}$	36.4
1	1.049	1.315	0.133	9–11	53.0
1$\frac{1}{4}$	1.380	1.660	0.140	9–11	69.6
1$\frac{1}{2}$	1.610	1.900	0.145	9–11	86.2
2	2.067	2.375	0.154	9–11	115.7
2$\frac{1}{2}$	2.469	2.875	0.203	9–10$\frac{1}{2}$	182.5
3	3.068	3.500	0.216	9–10$\frac{1}{2}$	238.9
3$\frac{1}{2}$	3.548	4.000	0.226	9–10$\frac{1}{4}$	287.7
4	4.026	4.500	0.237	9–10$\frac{1}{4}$	340.0
5	5.047	5.563	0.258	9–10	465.4
6	6.065	6.625	0.280	9–10	612.5

Table 100 Equivalent Resistivity Values

Volume Conductivity, Percent International Amended Copper Standard at 68°F	Equivalent Resistivity at 68°F, Volume: Ohm — Circular Mil/ft	Equivalent Resistivity at 68°F, Volume: Microhm — in.
52.5	19.754	1.2929
53.5	19.385	1.2687
53.8	19.277	1.2617
53.9	19.241	1.2593
54.0	19.206	1.2570
54.3	19.099	1.2501
55.0	18.856	1.2341
56.0	18.520	1.2121
56.5	18.356	1.2014
57.0	18.195	1.1908
59.0	17.578	1.1505
59.5	17.430	1.1408
61.0	17.002	1.1128
61.2	16.946	1.1091
61.3	16.918	1.1073
61.4	16.891	1.1055
61.5	16.863	1.1037
61.8	16.782	1.0983
62.0	16.727	1.0948
62.1	16.700	1.0931
62.2	16.674	1.0913
62.3	16.647	1.0896
62.4	16.620	1.0878

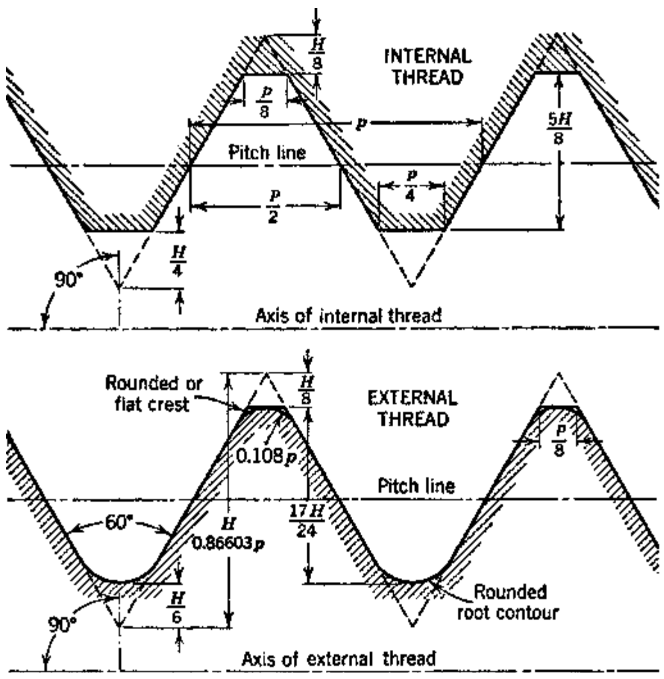
Table 101 Property Limits — Wire (Up to 0.374 in. Diameter)

Alloy and Temper	Ultimate Strength (ksi) Min	Ultimate Strength (ksi) Max	Electrical Conductivity[a] percent IACS at 68°F min
	1350		
1350-O	8.5	14.0	61.8
1350-H12 and H22	12.0	17.0	61.0
1350-H14 and H24	15.0	20.0	61.0
1350-H16 and H26	17.0	22.0	61.0
	8017		
8017-H212[b]	15.0	21.0	61.0
	8030		
8030-H221	15.0	22.0	61.0
	8176		
8176-H24	15.0	20.0	61.0
	8177		
8177-H221	15.0	22.0	61.0

Alloy and Temper	Specified Diameter (in.)	Ultimate Strength (ksi min) Individual[a]	Ultimate Strength (ksi min) Average[d]	Elongation Percent min in 10 in. Individual[a]	Elongation Percent min in 10 in. Average[d]	Electrical Conductivity[a] min percent IACS at 68°F
			1350			
1350-H19	0.0105–0.0500	23.0	25.0	—	—	
	0.0501–0.0600	27.0	29.0	1.2	1.4	
	0.0601–0.0700	27.0	28.5	1.3	1.5	
	0.0701–0.0800	26.5	28.0	1.4	1.6	
	0.0801–0.0900	26.0	27.5	1.5	1.6	
	0.0901–0.1000	25.5	27.0	1.5	1.6	
	0.1001–0.1100	24.5	26.0	1.5	1.6	61.0
	0.1101–0.1200	24.0	25.5	1.6	1.7	
	0.1201–0.1400	23.5	25.0	1.7	1.8	
	0.1401–0.1500	23.5	24.5	1.8	1.9	
	0.1501–0.1800	23.0	24.0	1.9	2.0	
	0.1801–0.2100	23.0	24.0	2.0	2.1	
	0.2101–0.2600	22.5	23.5	2.2	2.3	
			5005			
5005-H19	0.0601–0.0700	38.0	40.0	1.3	—	
	0.0701–0.0800	37.5	39.5	1.4	—	
	0.0801–0.0900	37.0	39.0	1.5	—	
	0.0901–0.1000	36.5	38.5	1.5	—	
	0.1001–0.1100	36.0	38.0	1.5	—	
5005-H19	0.1101–0.1200	35.5	37.5	1.6	—	53.5
	0.1201–0.1400	35.0	37.0	1.7	—	
	0.1401–0.1500	35.0	36.5	1.8	—	
	0.1501–0.1600	34.5	36.0	1.9	—	
	0.1601–0.2100	32.5	34.0	2.0	—	
	0.2101–0.2600	31.5	33.0	2.2	—	
			6201			
6201-T81	0.0612–0.1327	46.0	48.0	3.0	—	52.5
	0.1328–0.1878	44.0	46.0	3.0	—	
			8176			
8176-H24	0.0500–0.2040	15.0	17.0	10.0	—	61.0

[a] To convert conductivity to maximum resistivity use Table 100.
[b] Applicable up to 0.250 in.
[c] Any test in a lot.
[d] Average of all tests in a lot.

7 STANDARD SCREWS*



Standard Screw Threads The Unified and American Screw Threads included in Table 102 are taken from the publication of the American Standards Association, ASA B1.1 — 1949. The *coarse-thread series* is the former United States Standard Series. It is recommended for general use in engineering work where conditions do not require the use of a fine thread. The *fine-thread series* is the former "Regular Screw Thread Series" established by the Society of Automotive Engineers (SAE). The *fine-thread series* is recommended for general use in automotive and aircraft work and where special conditions require a fine thread. The *extra-fine-thread series* is the same as the former SAE fine series and the present SAE extra-fine series. It is used particularly in aircraft and aeronautical equipment where (a) thin-walled material is to be threaded; (b) thread depth of nuts clearing ferrules, coupling flanges, and so on, must be held to a minimum; and (c) a maximum practicable number of threads is required within a given thread length.

The method of designating a screw thread is by the use of the initial letters of the thread series, preceded by the nominal size (diameter in inches or the screw number) and number of threads per inch, all in Arabic numerals, and followed by the classification designation, with or without the pitch diameter tolerances or limits of size. An example of an external thread designation and its meaning is as follows:

Example 1

1/4″ — 20UNC — 2A

- Class of screw thread
- Thread series
- Number of threads per inch (n)
- Nominal size

A left-hand thread must be identified by the letters LH following the class designation. If no such designation is used, the thread is assumed to be right hand.

Classes of thread are distinguished from each other by the amounts of tolerance and allowance specified in ASA B1.1 — 1949.

*This section is extracted, with permission, from EMPIS Materials Selector.

Table 102 Standard Screw Threads

Sizes	Basic Major Diameter D (in.)	Threads per Inch n	Basic Pitch Diameter[a] E (in.)	Minor Diameter External Threads K_s (in.)	Minor Diameter Internal Threads K_n (in.)	Section at Minor Diameter at $D - 2h_b$) (in.^{2})	Stress Area[b] (in.^{2})
			Coarse-thread Series — UNC and NC (Basic Dimensions)				
1 (0.073)	0.0730	64	0.0629	0.0538	0.0561	0.0022	0.0026
2 (0.086)	0.0860	56	0.0744	0.0641	0.0667	0.0031	0.0036
3 (0.099)	0.0990	48	0.0855	0.0734	0.0764	0.0041	0.0048
4 (0.112)	0.1120	40	0.0958	0.0813	0.0849	0.0050	0.0060
5 (0.125)	0.1250	40	0.1088	0.0943	0.0979	0.0067	0.0079
6 (0.138)	0.1380	32	0.1177	0.0997	0.1042	0.0075	0.0090
8 (0.164)	0.1640	32	0.1437	0.1257	0.1302	0.0120	0.0139
10 (0.190)	0.1900	24	0.1629	0.1389	0.1449	0.0145	0.0174
12 (0.216)	0.2160	24	0.1889	0.1649	0.1709	0.0206	0.0240
$\frac{1}{4}$	**0.2500**	**20**	**0.2175**	**0.1887**	**0.1959**	**0.0269**	**0.0317**
$\frac{5}{16}$	**0.3125**	**18**	**0.2764**	**0.2443**	**0.2524**	**0.0454**	**0.0522**
$\frac{3}{8}$	**0.3750**	**16**	**0.3344**	**0.2983**	**0.3073**	**0.0678**	**0.0773**
$\frac{7}{16}$	**0.4375**	**14**	**0.3911**	**0.3499**	**0.3602**	**0.0933**	**0.1060**
$\frac{1}{2}$	0.5000	13	0.4500	0.4056	0.4167	0.1257	0.1416
$\frac{1}{2}$	**0.5000**	**12**	**0.4459**	**0.3978**	**0.4098**	**0.1205**	**0.1374**
$\frac{9}{16}$	**0.5625**	**12**	**0.5084**	**0.4603**	**0.4723**	**0.1620**	**0.1816**
$\frac{5}{8}$	**0.6250**	**11**	**0.5660**	**0.5135**	**0.5266**	**0.2018**	**0.2256**
$\frac{3}{4}$	**0.7500**	**10**	**0.6850**	**0.6273**	**0.6417**	**0.3020**	**0.3340**
$\frac{7}{8}$	**0.8750**	**9**	**0.8028**	**0.7387**	**0.7547**	**0.4193**	**0.4612**
1	**1.0000**	**8**	**0.9188**	**0.8466**	**0.8647**	**0.5510**	**0.6051**
$1\frac{1}{8}$	**1.1250**	**7**	**1.0322**	**0.9497**	**0.9704**	**0.6931**	**0.7627**
$1\frac{1}{4}$	**1.2500**	**7**	**1.1572**	**1.0747**	**1.0954**	**0.8898**	**0.9684**
$1\frac{3}{8}$	**1.3750**	**6**	**1.2667**	**1.1705**	**1.1946**	**1.0541**	**1.1538**
$1\frac{1}{2}$	**1.5000**	**6**	**1.3917**	**1.2955**	**1.3196**	**1.2938**	**1.4041**
$1\frac{3}{4}$	**1.7500**	**5**	**1.6201**	**1.5046**	**1.5335**	**1.7441**	**1.8983**
2	**2.0000**	**$4\frac{1}{2}$**	**1.8557**	**1.7274**	**1.7594**	**2.3001**	**2.4971**
$2\frac{1}{4}$	**2.2500**	**$4\frac{1}{2}$**	**2.1057**	**1.9774**	**2.0094**	**3.0212**	**3.2464**
$2\frac{1}{2}$	**2.5000**	**4**	**2.3376**	**2.1933**	**2.2294**	**3.7161**	**3.9976**
$2\frac{3}{4}$	**2.7500**	**4**	**2.5876**	**2.4433**	**2.4794**	**4.6194**	**4.9326**
3	**3.0000**	**4**	**2.8376**	**2.6933**	**2.7294**	**5.6209**	**5.9659**
$3\frac{1}{4}$	**3.2500**	**4**	**3.0876**	**2.9433**	**2.9794**	**6.7205**	**7.0992**
$3\frac{1}{2}$	**3.5000**	**4**	**3.3376**	**3.1933**	**3.2294**	**7.9183**	**8.3268**
$3\frac{3}{4}$	**3.7500**	**4**	**3.5876**	**3.4433**	**3.4794**	**9.2143**	**9.6546**
4	**4.0000**	**4**	**3.8376**	**3.6933**	**3.7294**	**10.6084**	**11.0805**

(*Continues*)

Table 102 (*Continued*)

Sizes	Basic Major Diameter D (in.)	Threads per Inch n	Basic Pitch Diameter[a] E (in.)	Minor Diameter External Threads K_s (in.)	Minor Diameter Internal Threads K_n (in.)	Section at Minor Diameter at $D - 2h_b$) (in.^{2})	Stress Area[b] (in.^{2})
			Fine-Thread Series — UNF and NF (Basic Dimensions)				
0 (0.060)	0.0600	80	0.0519	0.0447	0.0465	0.0015	0.0018
1 (0.073)	0.0730	72	0.0640	0.0560	0.0580	0.0024	0.0027
2 (0.086)	0.0860	64	0.0759	0.0668	0.0691	0.0034	0.0039
3 (0.099)	0.0990	56	0.0874	0.0771	0.0797	0.0045	0.0052
4 (0.112)	0.1120	48	0.0985	0.0864	0.0894	0.0057	0.0065
5 (0.125)	0.1250	44	0.1102	0.0971	0.1004	0.0072	0.0082
6 (0.138)	0.1380	40	0.1218	0.1073	0.1109	0.0087	0.0101
8 (0.164)	0.1640	36	0.1460	0.1299	0.1339	0.0128	0.0146
10 (0.190)	0.1900	32	0.1697	0.1517	0.1562	0.0175	0.0199
12 (0.216)	0.2160	28	0.1928	0.1722	0.1773	0.0226	0.0257
$\frac{1}{4}$	**0.2500**	**28**	**0.2268**	**0.2062**	**0.2113**	**0.0326**	**0.0362**
$\frac{5}{16}$	**0.3125**	**24**	**0.2854**	**0.2614**	**0.2674**	**0.0524**	**0.0579**
$\frac{3}{8}$	**0.3750**	**24**	**0.3479**	**0.3239**	**0.3299**	**0.0809**	**0.0876**
$\frac{7}{16}$	**0.4375**	**20**	**0.4050**	**0.3762**	**0.3834**	**0.1090**	**0.1185**
$\frac{1}{2}$	**0.5000**	**20**	**0.4675**	**0.4387**	**0.4459**	**0.1486**	**0.1597**
$\frac{9}{16}$	**0.5625**	**18**	**0.5264**	**0.4943**	**0.5024**	**0.1888**	**0.2026**
$\frac{5}{8}$	**0.6250**	**18**	**0.5889**	**0.5568**	**0.5649**	**0.2400**	**0.2555**
$\frac{3}{4}$	**0.7500**	**16**	**0.7094**	**0.6733**	**0.6823**	**0.3513**	**0.3724**
$\frac{7}{8}$	**0.8750**	**14**	**0.8286**	**0.7874**	**0.7977**	**0.4805**	**0.5088**
1	**1.0000**	**12**	**0.9459**	**0.8978**	**0.9098**	**0.6245**	**0.6624**
$1\frac{1}{8}$	**1.1250**	**12**	**1.0709**	**1.0228**	**1.0348**	**0.8118**	**0.8549**
$1\frac{1}{4}$	**1.2500**	**12**	**1.1959**	**1.1478**	**1.1598**	**1.0237**	**1.0721**
$1\frac{3}{8}$	**1.3750**	**12**	**1.3209**	**1.2728**	**1.2848**	**1.2602**	**1.3137**
$1\frac{1}{2}$	**1.5000**	**12**	**1.4459**	**1.3978**	**1.4098**	**1.5212**	**1.5799**
			Extra-Fine-Thread Series — NEF (Basic Dimensions)				
12 (0.216)	0.2160	32	0.1957	0.1777	0.1822	0.0242	0.0269
$\frac{1}{4}$	0.2500	32	0.2297	0.2117	0.2162	0.0344	0.0377
$\frac{5}{16}$	0.3125	32	0.2922	0.2742	0.2787	0.0581	0.0622
$\frac{3}{8}$	0.3750	32	0.3547	0.3367	0.3412	0.0878	0.0929
$\frac{7}{16}$	0.4375	28	0.4143	0.3937	0.3988	0.1201	0.1270
$\frac{1}{2}$	0.5000	28	0.4768	0.4562	0.4613	0.1616	0.1695
$\frac{9}{16}$	0.5625	24	0.5354	0.5114	0.5174	0.2030	0.2134
$\frac{5}{8}$	0.6250	24	0.5979	0.5739	0.5799	0.2560	0.2676
$\frac{11}{16}$	0.6875	24	0.6604	0.6364	0.6424	0.3151	0.3280
$\frac{3}{4}$	0.7500	20	0.7175	0.6887	0.6959	0.3685	0.3855
$\frac{13}{16}$	0.8125	20	0.7800	0.7512	0.7584	0.4388	0.4573
$\frac{7}{8}$	0.8750	20	0.8425	0.8137	0.8209	0.5153	0.5352
$\frac{15}{16}$	0.9375	20	0.9050	0.8762	0.8834	0.5979	0.6194

Table 102 (*Continued*)

Sizes	Basic Major Diameter D (in.)	Threads per Inch n	Basic Pitch Diameter[a] E (in.)	Minor Diameter External Threads K_s (in.)	Minor Diameter Internal Threads K_n (in.)	Section at Minor Diameter at $D - 2h_b$) (in.^{2})	Stress Area[b] (in.^{2})
			Fine-Thread Series — UNF and NF (Basic Dimensions)				
1	1.0000	20	0.9675	0.9387	0.9459	0.6866	0.7095
$1\frac{1}{16}$	1.0625	18	1.0264	0.9943	1.0024	0.7702	0.7973
$1\frac{1}{8}$	1.1250	18	1.0889	1.0568	1.0649	0.8705	0.8993
$1\frac{3}{16}$	1.1875	18	1.1514	1.1193	1.1274	0.9770	1.0074
$1\frac{1}{4}$	1.2500	18	1.2139	1.1818	1.1899	1.0895	1.1216
$1\frac{5}{16}$	1.3125	18	1.2764	1.2443	1.2524	1.2082	1.2420
$1\frac{3}{8}$	1.3750	18	1.3389	1.3068	1.3149	1.3330	1.3684
$1\frac{7}{16}$	1.4375	18	1.4014	1.3693	1.3774	1.4640	1.5010
$1\frac{1}{2}$	1.5000	18	1.4639	1.4318	1.4399	1.6011	1.6397
$1\frac{9}{16}$	1.5625	18	1.5264	1.4943	1.5024	1.7444	1.7846
$1\frac{5}{8}$	1.6250	18	1.5889	1.5568	1.5649	1.8937	1.9357
$1\frac{11}{16}$	1.6875	18	1.6514	1.6193	1.6274	2.0493	2.0929
$1\frac{3}{4}$	1.7500	16	1.7094	1.6733	1.6823	2.1873	2.2382
2	2.0000	16	1.9594	1.9233	1.9323	2.8917	2.9501

Note: Bold type indicates unified threads — UNC and UNF.
[a] British: effective diameter.
[b] The stress area is the assumed area of an externally threaded part which is used for the purpose of computing the tensile strength.

Table 103 ASA[a] Standard Bolts and Nuts

Nominal Size	Across Flats (in.)	Across Square Corners (in.)	Across Hex Corners (in.)	Thickness Unfinished (in.)	Thickness Semifinished (in.)
			Regular Bolt Heads		
$\frac{1}{4}$	$\frac{3}{8}$	0.498	0.413	$\frac{11}{64}$	$\frac{5}{32}$
$\frac{5}{16}$	$\frac{1}{2}$	0.665	0.552	$\frac{13}{64}$	$\frac{3}{16}$
$\frac{3}{8}$	$\frac{9}{16}$	0.747	0.620	$\frac{1}{4}$	$\frac{15}{64}$
$\frac{7}{16}$	$\frac{5}{8}$	0.828	0.687	$\frac{19}{64}$	$\frac{9}{32}$
$\frac{1}{2}$	$\frac{3}{4}$	0.995	0.826	$\frac{21}{64}$	$\frac{19}{64}$
$\frac{9}{16}$	$\frac{7}{8}$	1.163	0.966	$\frac{3}{8}$	$\frac{11}{32}$
$\frac{5}{8}$	$\frac{15}{16}$	1.244	1.033	$\frac{27}{64}$	$\frac{25}{64}$
$\frac{3}{4}$	$1\frac{1}{8}$	1.494	1.240	$\frac{1}{2}$	$\frac{15}{32}$
$\frac{7}{8}$	$1\frac{5}{16}$	1.742	1.447	$\frac{19}{32}$	$\frac{9}{16}$
1	$1\frac{1}{2}$	1.991	1.653	$\frac{21}{32}$	$\frac{19}{32}$
$1\frac{1}{8}$	$1\frac{11}{16}$	2.239	1.859	$\frac{3}{4}$	$\frac{11}{16}$

(*Continues*)

Table 103 (*Continued*)

Nominal Size	Across Flats (in.)	Across Square Corners (in.)	Across Hex Corners (in.)	Thickness Unfinished (in.)	Thickness Semifinished (in.)
$1\frac{1}{4}$	$1\frac{7}{8}$	2.489	2.066	$\frac{27}{32}$	$\frac{25}{32}$
$1\frac{3}{8}$	$2\frac{1}{16}$	2.738	2.273	$\frac{29}{32}$	$\frac{27}{32}$
$1\frac{1}{2}$	$2\frac{1}{4}$	2.986	2.480	1	$\frac{15}{16}$
$1\frac{5}{8}$	$2\frac{7}{16}$	3.235	2.686	$1\frac{3}{32}$	$1\frac{1}{32}$
$1\frac{3}{4}$	$2\frac{5}{8}$	3.485	2.893	$1\frac{5}{32}$	$1\frac{3}{32}$
$1\frac{7}{8}$	$2\frac{13}{16}$	3.733	3.100	$1\frac{1}{4}$	$1\frac{3}{16}$
2	3	3.982	3.306	$1\frac{11}{32}$	$1\frac{7}{32}$
$2\frac{1}{4}$	$3\frac{3}{8}$	4.479	3.719	$1\frac{1}{2}$	$1\frac{3}{8}$
$2\frac{1}{2}$	$3\frac{3}{4}$	4.977	4.133	$1\frac{21}{32}$	$1\frac{17}{32}$
$2\frac{3}{4}$	$4\frac{1}{8}$	5.476	4.546	$1\frac{53}{64}$	$1\frac{11}{16}$
3	$4\frac{1}{2}$	5.973	4.959	2	$1\frac{7}{8}$
			Heavy Bolt Heads		
$\frac{1}{2}$	$\frac{7}{8}$	1.167	0.969	$\frac{7}{16}$	$\frac{13}{32}$
$\frac{9}{16}$	$\frac{15}{16}$	1.249	1.037	$\frac{15}{32}$	$\frac{7}{16}$
$\frac{5}{8}$	$1\frac{1}{16}$	1.416	1.175	$\frac{17}{32}$	$\frac{1}{2}$
$\frac{3}{4}$	$1\frac{1}{4}$	1.665	1.383	$\frac{5}{8}$	$\frac{19}{32}$
$\frac{7}{8}$	$1\frac{7}{16}$	1.914	1.589	$\frac{23}{32}$	$\frac{11}{16}$
1	$1\frac{5}{8}$	2.162	1.796	$\frac{13}{16}$	$\frac{3}{4}$
$1\frac{1}{8}$	$1\frac{13}{16}$	2.411	2.002	$\frac{29}{32}$	$\frac{27}{32}$
$1\frac{1}{4}$	2	2.661	2.209	1	$\frac{15}{16}$
$1\frac{3}{8}$	$2\frac{3}{16}$	2.909	2.416	$1\frac{3}{32}$	$1\frac{1}{32}$
$1\frac{1}{2}$	$2\frac{3}{8}$	3.158	2.622	$1\frac{3}{16}$	$1\frac{1}{8}$
$1\frac{5}{8}$	$2\frac{9}{16}$	3.406	2.828	$1\frac{9}{32}$	$1\frac{7}{32}$
$1\frac{3}{4}$	$2\frac{3}{4}$	3.655	3.036	$1\frac{3}{8}$	$1\frac{5}{16}$
$1\frac{7}{8}$	$2\frac{15}{16}$	3.905	3.242	$1\frac{15}{32}$	$1\frac{13}{32}$
2	$3\frac{1}{8}$	4.153	3.449	$1\frac{9}{16}$	$1\frac{7}{16}$
$2\frac{1}{4}$	$3\frac{1}{2}$	4.652	3.862	$1\frac{3}{4}$	$1\frac{5}{8}$
$2\frac{1}{2}$	$3\frac{7}{8}$	5.149	4.275	$1\frac{15}{16}$	$1\frac{13}{16}$
$2\frac{3}{4}$	$4\frac{1}{4}$	5.646	4.688	$2\frac{1}{8}$	2
3	$4\frac{5}{8}$	6.144	5.102	$2\frac{5}{16}$	$2\frac{3}{16}$

Nominal Size	Width Across Flats (in.)	Width Across Corners: Square (in.)	Width Across Corners: Hex (in.)	Thickness Unfinished, Regular: Nuts (in.)	Thickness Unfinished, Regular: Jam Nuts (in.)	Thickness Semifinished, Regular: Nuts (in.)	Thickness Semifinished, Regular: Jam Nuts (in.)
			Regular Nuts and Regular Jam Nuts				
$\frac{1}{4}$	$\frac{7}{16}$	0.584	0.484	$\frac{7}{32}$	$\frac{5}{32}$	$\frac{13}{64}$	$\frac{9}{64}$
$\frac{5}{16}$	$\frac{9}{16}$	0.751	0.624	$\frac{17}{64}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{11}{64}$
$\frac{3}{8}$	$\frac{5}{8}$	0.832	0.691	$\frac{21}{64}$	$\frac{7}{32}$	$\frac{5}{16}$	$\frac{13}{64}$
$\frac{7}{16}$	$\frac{3}{4}$	1.000	0.830	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{23}{64}$	$\frac{15}{64}$
$\frac{1}{2}$	$\frac{13}{16}$	1.082	0.898	$\frac{7}{16}$	$\frac{5}{16}$	$\frac{27}{64}$	$\frac{19}{64}$
$\frac{9}{16}$	$\frac{7}{8}$	1.163	0.966	$\frac{1}{2}$	$\frac{11}{32}$	$\frac{31}{64}$	$\frac{21}{64}$
$\frac{5}{8}$	1	1.330	1.104	$\frac{35}{64}$	$\frac{3}{8}$	$\frac{17}{32}$	$\frac{23}{64}$
$\frac{3}{4}$	$1\frac{1}{8}$	1.494	1.240	$\frac{21}{32}$	$\frac{7}{16}$	$\frac{41}{64}$	$\frac{27}{64}$

Table 103 (*Continued*)

	Width Across	Width Across Corners		Thickness Unfinished, Regular		Thickness Semifinished, Regular	
Nominal Size	Flats (in.)	Square (in.)	Hex (in.)	Nuts (in.)	Jam Nuts (in.)	Nuts (in.)	Jam Nuts (in.)
$\frac{7}{8}$	$1\frac{5}{16}$	1.742	1.447	$\frac{49}{64}$	$\frac{1}{2}$	$\frac{3}{4}$	$\frac{31}{64}$
1	$1\frac{1}{2}$	1.991	1.653	$\frac{7}{8}$	$\frac{9}{16}$	$\frac{55}{64}$	$\frac{35}{64}$
$1\frac{1}{8}$	$1\frac{11}{16}$	2.239	1.859	1	$\frac{5}{8}$	$\frac{31}{32}$	$\frac{39}{64}$
$1\frac{1}{4}$	$1\frac{7}{8}$	2.489	2.066	$1\frac{3}{32}$	$\frac{3}{4}$	$1\frac{1}{16}$	$\frac{23}{32}$
$1\frac{3}{8}$	$2\frac{1}{16}$	2.738	2.273	$1\frac{13}{64}$	$\frac{13}{16}$	$1\frac{11}{64}$	$\frac{25}{32}$
$1\frac{1}{2}$	$2\frac{1}{4}$	2.986	2.480	$1\frac{5}{16}$	$\frac{7}{8}$	$1\frac{9}{32}$	$\frac{27}{32}$
$1\frac{5}{8}$	$2\frac{7}{16}$	3.235	2.686	$1\frac{27}{64}$	$\frac{15}{16}$	$1\frac{25}{64}$	$\frac{29}{32}$
$1\frac{3}{4}$	$2\frac{5}{8}$	3.485	2.893	$1\frac{17}{32}$	1	$1\frac{1}{2}$	$\frac{31}{32}$
$1\frac{7}{8}$	$2\frac{13}{16}$	3.733	3.100	$1\frac{41}{64}$	$1\frac{1}{16}$	$1\frac{39}{64}$	$1\frac{1}{32}$
2	3	3.982	3.306	$1\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{23}{32}$	$1\frac{3}{32}$
$2\frac{1}{4}$	$3\frac{3}{8}$	4.479	3.719	$1\frac{31}{32}$	$1\frac{1}{4}$	$1\frac{59}{64}$	$1\frac{13}{64}$
$2\frac{1}{2}$	$3\frac{3}{4}$	4.977	4.133	$2\frac{3}{16}$	$1\frac{1}{2}$	$2\frac{9}{64}$	$1\frac{29}{64}$
$2\frac{3}{4}$	$4\frac{1}{8}$	5.476	4.546	$2\frac{13}{32}$	$1\frac{5}{8}$	$2\frac{23}{64}$	$1\frac{37}{64}$
3	$4\frac{1}{2}$	5.973	4.959	$2\frac{5}{8}$	$1\frac{3}{4}$	$2\frac{37}{64}$	$1\frac{45}{64}$
				Heavy Nuts and Heavy Jam Nuts			
$\frac{1}{4}$	$\frac{1}{2}$	0.670	0.556	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{15}{64}$	$\frac{11}{64}$
$\frac{5}{16}$	$\frac{19}{32}$	0.794	0.659	$\frac{5}{16}$	$\frac{7}{32}$	$\frac{19}{64}$	$\frac{13}{64}$
$\frac{3}{8}$	$\frac{11}{16}$	0.919	0.763	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{23}{64}$	$\frac{15}{64}$
$\frac{7}{16}$	$\frac{25}{32}$	1.042	0.865	$\frac{7}{16}$	$\frac{9}{32}$	$\frac{27}{64}$	$\frac{17}{64}$
$\frac{1}{2}$	$\frac{7}{8}$	1.167	0.969	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{31}{64}$	$\frac{19}{64}$
$\frac{9}{16}$	$\frac{15}{16}$	1.249	1.037	$\frac{9}{16}$	$\frac{11}{32}$	$\frac{35}{64}$	$\frac{21}{64}$
$\frac{5}{8}$	$1\frac{1}{16}$	1.416	1.175	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{39}{64}$	$\frac{23}{64}$
$\frac{3}{4}$	$1\frac{1}{4}$	1.665	1.382	$\frac{3}{4}$	$\frac{7}{16}$	$\frac{47}{64}$	$\frac{27}{64}$
$\frac{7}{8}$	$1\frac{7}{16}$	1.914	1.589	$\frac{7}{8}$	$\frac{1}{2}$	$\frac{55}{64}$	$\frac{31}{64}$
1	$1\frac{5}{8}$	2.162	1.796	1	$\frac{9}{16}$	$\frac{63}{64}$	$\frac{35}{64}$
$1\frac{1}{8}$	$1\frac{13}{16}$	2.411	2.002	$1\frac{1}{8}$	$\frac{5}{8}$	$1\frac{7}{64}$	$\frac{39}{64}$
$1\frac{1}{4}$	2	2.661	2.209	$1\frac{1}{4}$	$\frac{3}{4}$	$1\frac{7}{32}$	$\frac{23}{32}$
$1\frac{3}{8}$	$2\frac{3}{16}$	2.909	2.416	$1\frac{3}{8}$	$\frac{13}{16}$	$1\frac{11}{32}$	$\frac{25}{32}$
$1\frac{1}{2}$	$2\frac{3}{8}$	3.158	2.622	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{15}{32}$	$\frac{27}{32}$
$1\frac{5}{8}$	$2\frac{9}{16}$	3.406	2.828	$1\frac{5}{8}$	$\frac{15}{16}$	$1\frac{19}{32}$	$\frac{29}{32}$
$1\frac{3}{4}$	$2\frac{3}{4}$	3.656	3.035	$1\frac{3}{4}$	1	$1\frac{23}{32}$	$\frac{31}{32}$
$1\frac{7}{8}$	$2\frac{15}{16}$	3.905	3.242	$1\frac{7}{8}$	$1\frac{1}{16}$	$1\frac{27}{32}$	$1\frac{1}{32}$
2	$3\frac{1}{8}$	4.153	3.449	2	$1\frac{1}{8}$	$1\frac{31}{32}$	$1\frac{3}{32}$
$2\frac{1}{4}$	$3\frac{1}{2}$	4.652	3.862	$2\frac{1}{4}$	$1\frac{1}{4}$	$2\frac{13}{64}$	$1\frac{13}{64}$
$2\frac{1}{2}$	$3\frac{7}{8}$	5.149	4.275	$2\frac{1}{2}$	$1\frac{1}{2}$	$2\frac{29}{64}$	$1\frac{29}{64}$
$2\frac{3}{4}$	$4\frac{1}{4}$	5.646	4.688	$2\frac{3}{4}$	$1\frac{5}{8}$	$2\frac{45}{64}$	$1\frac{37}{64}$
3	$4\frac{5}{8}$	6.144	5.102	3	$1\frac{3}{4}$	$2\frac{61}{64}$	$1\frac{45}{64}$
$3\frac{1}{4}$	5	6.643	5.515	$3\frac{1}{4}$	$1\frac{7}{8}$	$3\frac{3}{16}$	$1\frac{13}{16}$
$3\frac{1}{2}$	$5\frac{3}{8}$	7.140	5.928	$3\frac{1}{2}$	2	$3\frac{7}{16}$	$1\frac{15}{16}$
$3\frac{3}{4}$	$5\frac{3}{4}$	7.637	6.341	$3\frac{3}{4}$	$2\frac{1}{8}$	$3\frac{11}{16}$	$2\frac{1}{16}$
4	$6\frac{1}{8}$	8.135	6.755	4	$2\frac{1}{4}$	$3\frac{15}{16}$	$2\frac{3}{16}$

Table 103 (*Continued*)

	Regular Slotted Nuts Semifinished			Heavy Slotted Nuts Semifinished				
	Width			Width			Slot	
Nominal Size	Across Flats (in.)	Across Corners (in.)	Thickness (in.)	Across Flats (in.)	Across Corners (in.)	Thickness (in.)	Width (in.)	Depth (in.)
$\frac{1}{4}$	$\frac{7}{16}$	0.485	$\frac{13}{64}$	$\frac{1}{2}$	0.556	$\frac{15}{64}$	$\frac{5}{64}$	$\frac{3}{32}$
$\frac{5}{16}$	$\frac{9}{16}$	0.624	$\frac{1}{4}$	$\frac{19}{32}$	0.659	$\frac{19}{64}$	$\frac{3}{32}$	$\frac{3}{32}$
$\frac{3}{8}$	$\frac{5}{8}$	0.691	$\frac{5}{16}$	$\frac{11}{16}$	0.763	$\frac{23}{64}$	$\frac{1}{8}$	$\frac{1}{8}$
$\frac{7}{16}$	$\frac{3}{4}$	0.830	$\frac{23}{64}$	$\frac{25}{32}$	0.865	$\frac{27}{64}$	$\frac{1}{8}$	$\frac{5}{32}$
$\frac{1}{2}$	$\frac{13}{16}$	0.898	$\frac{27}{64}$	$\frac{7}{8}$	0.969	$\frac{31}{64}$	$\frac{5}{32}$	$\frac{5}{32}$
$\frac{9}{16}$	$\frac{7}{8}$	0.966	$\frac{31}{64}$	$\frac{15}{16}$	1.037	$\frac{35}{64}$	$\frac{5}{32}$	$\frac{3}{16}$
$\frac{5}{8}$	1	1.104	$\frac{17}{32}$	$1\frac{1}{16}$	1.175	$\frac{39}{64}$	$\frac{3}{16}$	$\frac{7}{32}$
$\frac{3}{4}$	$1\frac{1}{8}$	1.240	$\frac{41}{64}$	$1\frac{1}{4}$	1.382	$\frac{47}{64}$	$\frac{3}{16}$	$\frac{1}{4}$
$\frac{7}{8}$	$1\frac{5}{16}$	1.447	$\frac{3}{4}$	$1\frac{7}{16}$	1.589	$\frac{55}{64}$	$\frac{3}{16}$	$\frac{1}{4}$
1	$1\frac{1}{2}$	1.653	$\frac{55}{64}$	$1\frac{5}{8}$	1.796	$\frac{63}{64}$	$\frac{1}{4}$	$\frac{9}{32}$
$1\frac{1}{8}$	$1\frac{11}{16}$	1.859	$\frac{31}{32}$	$1\frac{13}{16}$	2.002	$1\frac{7}{64}$	$\frac{1}{4}$	$\frac{11}{32}$
$1\frac{1}{4}$	$1\frac{7}{8}$	2.066	$1\frac{1}{16}$	2	2.209	$1\frac{7}{32}$	$\frac{5}{16}$	$\frac{3}{8}$
$1\frac{3}{8}$	$2\frac{1}{16}$	2.273	$1\frac{11}{64}$	$2\frac{3}{16}$	2.416	$1\frac{11}{32}$	$\frac{5}{16}$	$\frac{3}{8}$
$1\frac{1}{2}$	$2\frac{1}{4}$	2.480	$1\frac{9}{32}$	$2\frac{3}{8}$	2.622	$1\frac{15}{32}$	$\frac{3}{8}$	$\frac{7}{16}$
$1\frac{5}{8}$	$2\frac{7}{16}$	0.686	$1\frac{25}{64}$	$2\frac{9}{16}$	2.828	$1\frac{19}{32}$	$\frac{3}{8}$	$\frac{7}{16}$
$1\frac{3}{4}$	$2\frac{5}{8}$	2.893	$1\frac{1}{2}$	$2\frac{3}{4}$	3.035	$1\frac{23}{32}$	$\frac{7}{16}$	$\frac{1}{2}$
$1\frac{7}{8}$	$2\frac{13}{16}$	3.100	$1\frac{39}{64}$	$2\frac{15}{16}$	3.242	$1\frac{27}{32}$	$\frac{7}{16}$	$\frac{9}{16}$
2	3	3.306	$1\frac{23}{32}$	$3\frac{1}{8}$	3.449	$1\frac{31}{32}$	$\frac{7}{16}$	$\frac{9}{16}$
$2\frac{1}{4}$	$3\frac{3}{8}$	3.719	$1\frac{59}{64}$	$3\frac{1}{2}$	3.862	$2\frac{13}{64}$	$\frac{7}{16}$	$\frac{9}{16}$
$2\frac{1}{2}$	$3\frac{3}{4}$	4.133	$2\frac{9}{64}$	$3\frac{7}{8}$	4.275	$2\frac{29}{64}$	$\frac{9}{16}$	$\frac{11}{16}$
$2\frac{3}{4}$	$4\frac{1}{8}$	4.546	$2\frac{23}{64}$	$4\frac{1}{4}$	4.688	$2\frac{45}{64}$	$\frac{9}{16}$	$\frac{11}{16}$
3	$4\frac{1}{2}$	4.959	$2\frac{37}{64}$	$4\frac{5}{8}$	5.102	$2\frac{61}{64}$	$\frac{5}{8}$	$\frac{3}{4}$

[a] ANSI standards B18.2.1 — 1981, B18.2.2 — 1972 (R1983), B18.6.3 — 1972 (R1983).

Selection of Screws By definition, a *screw* is a fastener that is intended to be torqued by the head. Screws are the most widely used method of assembly despite recent technical advances of adhesives, welding, and other joining techniques. Use of screws is essential in those applications that require ease of disassembly for normal maintenance and service. There is no real economy if savings made in factory installation create service problems later. There are many types of screws, and each variety will be treated separately. Material selection is generally common to all types of screws.

Material. Not all materials are suitable for the processes used in the manufacture of fasteners. Large-volume users or those with critical requirements can be very selective in their choice of materials. Low-volume users or those with noncritical applications would be wise to permit a variety of materials in a general category in order to improve availability and lower cost. For example, it is usually desirable to specify low-carbon steel or 18-8-type stainless steel* rather than ask for a specific grade.

Low-carbon steel is widely used in the manufacture of fasteners where lowest cost is desirable and tensile strength requirements are $\sim$50,000 psi. If corrosion is a problem, these fasteners can be plated either electrically or mechanically. Zinc or cadmium plating is used in most applications. Other finishes include nickel, chromium, copper, tin, and silver electroplating; electroless nickel and other immersion coatings; hot dip galvanizing; and phosphate coatings.

*Manufacturer may use UNS—S30200, S30300, S30400, S30500 (AISI type 302, 303, 304, or 305) depending upon quantity, diameter, and manufacturing process.

Medium-carbon steel, quenched, and tempered is widely used in applications requiring tensile strengths from 90,000 to 120,000 psi. Alloy steels are used in applications requiring tensile strengths from 115,000 to 180,000 psi, depending on the grade selected. Where better corrosion resistance is required, 300 series stainless steel can be specified. The 400 series stainless steel is used if it is necessary to have a corrosion-resistant material that can be hardened and tempered by heat treatment.

For superior corrosion resistance, materials such as brass, bronze, aluminum, or nickel are sometimes used in the manufacture of fasteners. If strength is no problem, plastics such as nylons are used in severe corrosion applications.

Drivability. When selecting a screw, thought must be given to the means of driving for assembly and disassembly as well as the head shape. Most screw heads provide a slot, a recess, or a hexagon shape as a means of driving. The slotted screw is the least preferred driving style and serves only when appearance must be combined with ease of disassembly with a common screwdriver. Only a limited amount of torque can be applied with a screwdriver. A slot can become inoperative after repeated disassembly destroys the edge of the wall that the blade of the screwdriver bears against. The hexagon head is preferred for the following reasons:

Least likely to accidentally spin out (thereby marring the surface of the product)

Lowest initial cost

Adaptable to high-speed power drive

Minimum worker fatigue

Ease of assembly in difficult places

Permits higher driving torque, especially in large sizes where strength is important

Contains no recess to become clogged with dirt and interfere with driving

Contains no recess to weaken the head

Unless frequent field disassembly is required, use of the unslotted hex head is preferred.

Appearance is the major disadvantage of the hex head, and this one factor is judged sufficient to eliminate it from consideration for the front or top of products.

The recessed head fastener is widely used and becomes the first choice for appearance applications. It usually costs more than a slot or a hexagon shape. There are many kinds of recesses. The Phillips and Phillips POZIDRIV are most widely used. To a lesser extent the Frearson, clutch-type, hexagonal, and fluted socket heads are used. For special applications, proprietary types of tamper-resistant heads can be selected (Fig. 1).

The recessed head has some of the same advantages as the hex head (see preceding list). It also has improved appearance. The Phillips POZIDRIV is slowly replacing the Phillips recess. The POZIDRIV recess can be readily identified by four radial lines centered between each recess slot. These slots are a slight modification of the conventional Phillips recess. This change improves the fit between the driver and the recess, thus minimizing the possibility of marring a surface from accidental spinout of the driver as well as increasing the life of the driver. The POZIDRIV design is recommended in high-production applications requiring high driving torques. The POZIDRIV

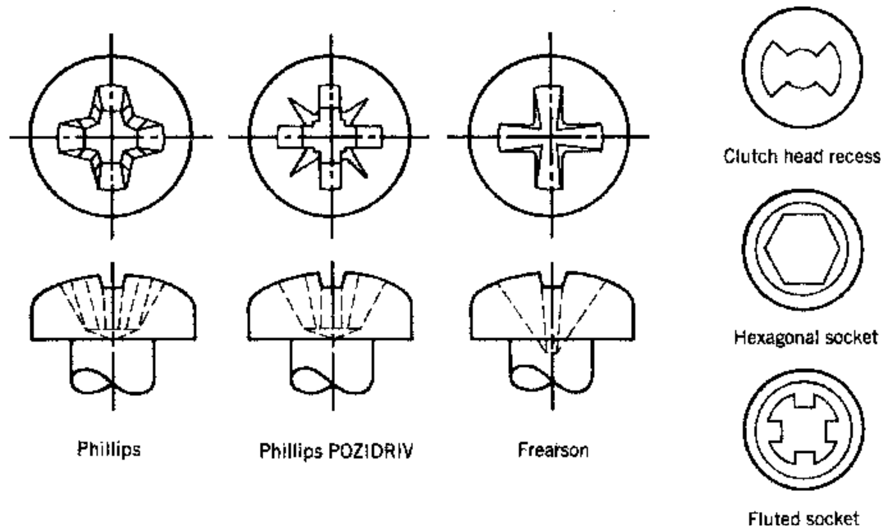


Fig. 1 Recessed head fasteners.

recess usually sells at a high-production applications requiring high driving torques. The POZIDRIV recess usually sells at a slightly higher price than the conventional Phillips recess, but some suppliers will furnish either at the same price. The savings resulting from longer tool life will usually justify the higher initial cost.

A conventional Phillips driver could be used to install or disassemble a POZIDRIV screw. However, a POZIDRIV driver should be used with a POZIDRIV screw in order to take advantage of the many features inherent in the new design. To avoid confusion, it should be clearly understood that a POZIDRIV driver cannot be used to install or remove a conventional Phillips head screw.

A Frearson recess is a somewhat different design than a Phillips recess and has the big advantage that one driving tool can be used for all sizes whereas a Phillips may require four driving tools in the range from no. 2 (0.086-in.) to 3/8 (0.375-in.) screw size. This must be balanced against the following disadvantages:

Limited availability.

Greater penetration of the recess means thinner walls between the bottom of the recess and the outer edge of the screw, which tends to weaken the head.

The sharp point of the driver can easily scratch or otherwise mar the surface of the product if it accidently touches.

Although one driver can be used for all sizes, for optimum results, different size drivers are recommended for installing various screw sizes, thus minimizing the one real advantage of the Frearson recess.

The hexagon and fluted socket head cap screws are only available in expensive high-strength alloy steel. Its unique small outside diameter or cylindrical head is useful on flanges, counterbored holes, or other locations where clearances are restricted. Such special applications may justify the cost of a socket head cap screw. Appreciable savings can be made in other applications by substitution of a hexagon head screw.

Despite any claims to the contrary, the dimensional accuracy of hexagon socket head cap screws is no better than that of other cold-headed products, and there is no merit in close-thread tolerances, which are advocated by some manufacturers of these products. The high prices, therefore, should be justified solely on the basis of possible space savings in using the cylindrical head.

The fluted socket is not as readily available and should only be considered in the very small sizes where a hexagon key tends to round out the socket. The fluted socket offers spline design so that the key will neither slip nor be subject to excessive wear.

Many types of special recesses are tamper resistant. In most of these designs, the recess is an unusual shape requiring a special tool for assembly and disassembly. A readily available driving tool such as a screwdriver or hexagon key would not fit the recess. The purpose of a tamper-resistant fastener is to prevent unauthorized removal of parts and equipment. Their protection is needed on any product located in public places to discourage vandalism and thievery. They may also be necessary on some consumer products as a safety measure to protect the amateur repairman from injury or to prevent him from causing serious damage to equipment. With product liability mania what it is today, the term "tamperproof" has all but disappeared. Now the fasteners are called "tamper resistant." They are the same as they were under their previous name, but the new term better reflects their true capabilities. Any skilled thief with ample time and proper tools can saw, drill, blast, or otherwise disassemble any tamper-resistant fastener. Therefore, these fasteners are intended only to discourage the casual thief or amateur tinkerer and make it more difficult for a skilled professional. Whatever the choice of fastener design, it is essential that hardened material be specified. No fastener is ever truly tamperproof, but hardened steel helps. Fasteners made of soft material can be disassembled easily by sawing a slot, hammering with a chisel, or drilling a hole and using an extraction bit.

Head Shapes The following information is equally applicable to all types of recesses as well as a slotted head. For simplification only slotted screws are shown.

The pan head is the most widely used and is intended to replace the round, binding, and truss heads in order to keep varieties to a minimum. It is preferred because it presents the best combination of appearance with adequate head height to minimize weakness due to depth of penetration of the recess (Fig. 2).

The round head was widely used in the past (Fig. 3). It has since been delisted as an American National Standard. Give preference to pan heads on all new designs. Figure 4 shows the superiority of the pan head: The high edge of the pan head at its periphery,

Fig. 2 Pan head.

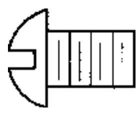


Fig. 3 Round head.

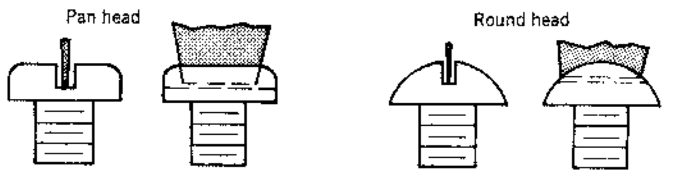


Fig. 4 Drive-slot engagement.

where driving action is most effective, provides superior driver-slot engagement and reduces the tendency to chew away the metal at the edge of the slot.

The flat head is used where a flush surface is required. The countersunk section aids in centering the screw (Fig. 5).

The oval head is similar to a flat head except that instead of a flush surface it presents a low silhouette that improves the appearance (Fig. 6).

The truss head is similar to the round head except that the head is shallower and has a larger diameter. It is used where extra bearing surface is required for extra holding power or where the clearance hole is oversized or the material is soft. It also presents a low silhouette that improves the appearance (Fig. 7).

The binding head is similar to the pan head and is commonly used for electrical connections where an undercut is usually specified to bind and prevent the fraying of stranded wire (Fig. 8).

The fillister head has the smallest diameter for a given shank size. It also has a deep slot that allows a higher torque to be applied during assembly. It is not as readily available or as widely used as some of the other head styles (Fig. 9).

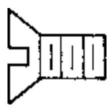


Fig. 5 Flat head.

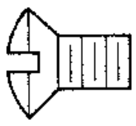


Fig. 6 Oval head.

Fig. 7 Truss head.

Fig. 8 Binding head.

Fig. 9 Fillister head.

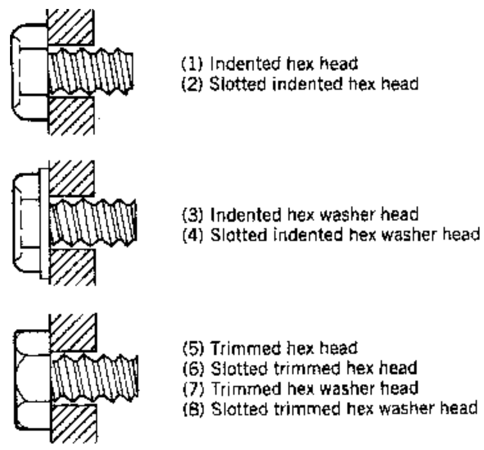


Fig. 10 Hex head.

The advantages of a hex head are listed in the discussion on drivability. This type head is available in eight variations (Fig. 10).

The indented design is lowest cost as the hex is completely cold upset in a counterbore die and possesses an identifying depression in the top surface of the head.

The trimmed design requires an extra operation to produce clean sharp corners with no indentation. Appearance is improved and there is no pocket on top to collect moisture.

The washer design has a larger bearing surface to spread the load over a wider area. The washer is an integral part of the head and also serves to protect the finish of the assembly from wrench disfigurement.

The slot is used to facilitate field service. It adds to the cost, weakens the head, and limits the amount of tightening torque that can be applied. A slot is unnecessary in high-production factory installation.

Any given location should standardize on one or possibly two of the eight variations.

Types of Screws

Machine Screws. Machine screws are meant to be assembled in tapped holes, either into a product or into a nut. The screw threads of a machine screw are readily available in American National Standard Unified Inch Coarse and Fine Thread series. They are generally considered for applications where the material to be joined is too hard, too weak, too brittle, or too thick to take a tapping screw. It is also used in applications where the assembly requires a fastener made of a material that cannot be hardened enough to make its own thread, such as brass or nylon machine screws. Applications requiring freedom from dust or particles of any kind cannot use thread-cutting screws and, therefore, must be joined by machine screws or a tapping screw which forms or rolls a thread.

There are many combinations of head styles, shapes, and materials.

Self-Tapping Screws. There are many different types of self-tapping screws commercially available. The following three types are capable of creating an internal thread by being twisted into a smooth hole:

1. Thread-forming screws
2. Thread-cutting screws
3. Thread-rolling screws

The following two types create their own opening before generating the thread:

4. Self-drilling and tapping screws
5. Self-extruding and tapping screws

1. **Thread-Forming Screws.** Thread-forming screws create an internal thread by forming or squeezing material. They rely on the pressure of the screw thread to force a mating thread into the workpiece. They are applicable in materials where large internal stresses are permissible or desirable to increase resistance to loosening. They are generally used to fasten sheet metal parts. They cannot be used to join brittle materials, such as plastics, because the stresses created in the workpiece can cause cracking. The following types of thread-forming screws are commonly used:

Types A and AB. Type AB screws have a spaced thread. This means that each thread is spaced further away from its adjacent thread than the popular machine screw series. They also have a gimlet point for ease in entering a predrilled hole. This type of screw is primarily intended to be used in sheet metal with a thickness from 0.015 in. (0.38 mm) to 0.05 in. (1.3 mm), resin-impregnated plywood, natural woods, and asbestos compositions.

Type AB screws were introduced several years ago to replace the type A screws. The type A screw is the same as the type AB except for a slightly wider spacing of the threads. Both are still available and can be used interchangeably. The big advantage of the type AB screw is that its threads are spaced exactly as the type B screws to be discussed later. In the interest of standardization it is recommended that type AB screws be used in place of either the type A or the type B series (Fig. 11).

Type B. Type B screws have the same spacing as type AB screws. Instead of a gimlet point, they have a blunt point with incomplete threads at the point. This point makes the type B more suitable for thicker metals and blind holes. The type B screws can be used in any of the applications listed under type AB. In addition the type B screw can be used in sheet metal up to a thickness of 0.200 in. (5 mm) and in nonferrous castings (Fig. 12).

Type C. Type C screws look like type B screws except that threads are spaced to be exactly the same as a machine screw thread and may be used to replace a machine screw in the field. They are recommended for general use in metal 0.030–0.100 in. (0.76–2.54 mm) thick. It should be recognized that in specific applications, involving long thread engagement or hard materials, this type of screw requires extreme driving torques.

2. **Thread-Cutting Screws.** Thread-cutting screws create an internal thread by actual removal of material from the internal hole. The design of the cavity to provide space for the chips and the design of the cutting edge differ with each type. They are used in place of the thread-forming type for applications

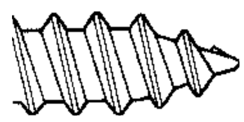


Fig. 11 Type AB.

Fig. 12 Type B.

in materials where disruptive internal stresses are undesirable or where excessive driving torques are encountered. The following types of thread-cutting screws are commonly used:

Type BT (Formerly Known as Type 25). Type BT screws have a spaced thread and a blunt point similar to the type B screw. In addition they have one cutting edge and a wide chip cavity. These screws are primarily intended for use in very friable plastics such as urea compositions, asbestos, and other similar compositions. In these materials, a larger space between threads is required to produce a satisfactory joint because it reduces the buildup of internal stresses that fracture brittle plastic when a closer spaced thread is used. The wide cutting slot creates a large cutting edge and permits rapid deflection of the chips to produce clean mating threads. For best results all holes should be counterbored to prevent fracturing the plastic. Use of this type screw eliminates the need to use tapped metallic inserts in plastic materials (Fig. 13).

Type ABT. Type ABT screws are the same as type BT screws except that they have a gimlet point similar to a type AB screw. This design is not recognized as an American National Standard and should only be selected for large-volume applications (over 50,000 pieces of one size and type). It is primarily intended for use in plastic for the same reasons as listed for type BT screws (Fig. 14).

Type D (Formerly Known as Type 1). Type D screws have threads of machine screw diameter–pitch combinations approximating unified form with a blunt point and tapered entering threads. In addition a slot is cut off center with one side on the center line. This radial side of the slot creates the sharp serrated cutting edge such as formed on a tap. The slot leaves a thinner section on one side of the screw that collapses and helps concentrate the pressure on the cutting edge. This screw is suitable for use in all thicknesses of metals (Fig. 15).

Type F. Type F screws are identical to type D except that instead of one slot there are several slots cut at a slight angle to the axis of the thread. This screw is suitable for use in all thicknesses of metals and can be used interchangeably with a type D screw in many applications. However, the type F screw is superior to the type D screw for tapping into cast iron and permits the use of a smaller pilot hole (Fig. 16).

Fig. 13 Type BT.

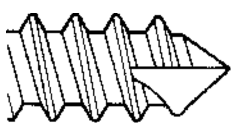


Fig. 14 Type ABT.

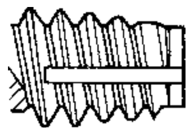


Fig. 15 Type D.

Fig. 16 Type F.

Type D or Type F. Because in many applications these two types can be used interchangeably with the concomitant advantages of simpler inventory and increased availability, a combined specification is often issued permitting the supplier to furnish either type.

Type T (Formerly Known as Type 23). Type T screws are similar to type D and type F except that they have an acute rake angle cutting edge. The cut in the end of the screw is designed to eliminate a pocket that confines the chips. The shape of the slot is such that the chips are forced ahead of the screw as it is driven. This screw is suitable for plastics and other soft materials when a standard machine screw series thread is desired. It is used in place of type D and type F when more chip room is required because of deep penetration (Fig. 17).

Type BF. Type BF screws are intended for use in plastics. The wide thread pitch reduces the buildup of internal stresses that fracture brittle plastics when a smaller thread pitch is used. The screw has a blunt point and tapered entering threads with several cutting edges and chip cavity (Fig. 18).

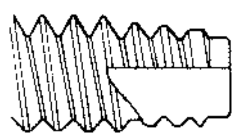


Fig. 17 Type T.

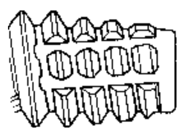


Fig. 18 Type BF.

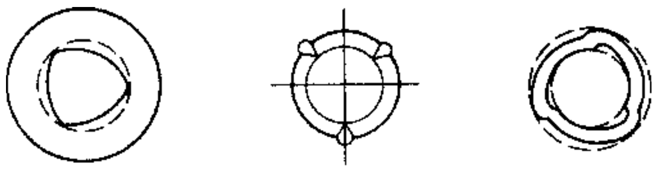


Fig. 19 Thread-rolling screws.

3. **Thread-Rolling Screws.** Thread-rolling screws (see Fig. 19) form an internal thread by flowing metal and thus do not cut through or disrupt the grain flow lines of materials as do thread-cutting screws. The screw compacts and work hardens the material, thereby forming strong, smoothly burnished internal threads. The screws have the threads of machine screw diameter–pitch combinations. This type screw is ideal for applications where chips can cause electrical shorting of equipment or jamming of delicate mechanism. Freedom from formation of chips eliminates the costly problem of cleaning the product of chips and burrs as would otherwise be required.

The ratio of driving torque to stripping torque is approximately 1 : 8 for a thread-rolling screw as contrasted to 1 : 3 for a conventional tapping screw. This higher ratio permits the driver torque release to be set well over the required driving torque and yet safely below the stripping torque. This increased ratio minimizes poor fastening due to stripped threads or inadequate seating of the screws.

Plastite is intended for use in filled or unfilled thermoplastics and some of the thermosetting plastics. The other three types are intended for use in metals. At present, there are no data to prove the superiority of one type over another.

4. **Self-Drilling and Tapping Screws.** The self-drilling and tapping screw (Fig. 20) drills its own hole and forms a mating thread, thus making a complete fastening in a single operation. Assembly labor is reduced by eliminating the need to predrill holes at assembly and by solving the problem of hole alignment. These screws must complete their metal-drilling function and fully penetrate the material before the screw thread can engage and begin its advancement. In order to meet this requirement, the unthreaded point length must be equal to or greater than the material thickness to be drilled. Therefore, there is a strict limitation on minimum and maximum material thickness that varies with screw size. There are many different styles and types of self-drilling and tapping screws to meet specific needs.

5. **Self-Extruding Screws.** Self-extruding screws provide their own extrusion as they are driven into an inexpensively produced punched hole. The resulting extrusion height is several times the base material thickness. This type screw is suitable for material in thicknesses up to 0.048 in. (1.2 mm). By increasing the thread engagement, these screws increase the differential between driving and stripping torque and provide greater pull-out strength. Since they do not produce chips, they are excellent for grounding sheet metal for electrical connections (Fig. 21).

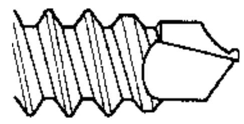


Fig. 20 Self-drilling and tapping screws.

Fig. 21 Self-extruding screw.

There is almost no limit to the variety of head styles, thread forms, and screw materials that are available commercially. The listing only shows representative examples. Users should attempt to keep varieties to a minimum by carefully selecting those variations that best meet the needs of their type of product.

Set Screws. Set screws are available in various combinations of head and point style as well as material and are used as locking, locating, and adjustment devices. The common head styles are slotted headless, square head, hexagonal socket, and fluted socket. The slotted headless has the lowest cost and can be used in a counterbored hole to provide a flush surface. The square head is applicable for location or adjustment of static parts where the projecting head is not objectionable. Its use should be avoided on all rotating parts. The hexagonal socket head can be used in a counterbored hole to provide a flush surface. It permits greater torque to be applied than with a slotted headless design. Fluted sockets are useful in very small

Table 104 Holding Power of Flat or Cup Point Set Screws

d (in.)	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$
P (lb)	100	168	256	366	500	658	840	1280	1830	2500	3388	4198

diameters, that is, no. 6 (0.138 in.) and under, where hexagon keys tend to round out the socket in hexagonal socket set screws. Set screws should not be used to transmit large amounts of torque, particularly under shock torsion loads. Increased torsion loads may be carried by two set screws located 120° apart.

The following points are available with the head styles discussed: The cup point (Table 104) is the standard stock point for all head shapes and is recommended for all general locking purposes. Flats are recommended on round shafts when close fits are used and it is desirable to avoid interference in disassembling parts because of burrs produced by action of the cup point or when the flats are desired to increase torque transmission. When flats are not used, it is recommended that the minimum shaft diameter be not less than four times the cup diameter since otherwise the whole cup may not be in contact with the shaft. The self-locking cup point has limited availability. It has counterclockwise knurls to prevent the screw from working loose even in poorly tapped holes (Fig. 22).

When oval points are used, the surface it contacts should be grooved or spotted to the same general contour as the point to assure good seating. It is used where frequent adjustment is necessary without excessive deformation of the part against which it bears (Fig. 23).

When flat points are used, it is customary to grind a flat on the shaft for better point contact. This point is preferred where wall thickness is thin and on top of plugs made of any soft material (Fig. 24).

When the cone point is used, it is recommended that the angle of countersink be as nearly as possible the angle of screw point for the best efficiency. Cone point set screws have some application as pivot points. It is used where permanent location of parts is required. Because of penetration, it has the highest axial and torsional holding power of any point (Fig. 25).

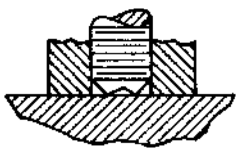


Fig. 22 Cup point.

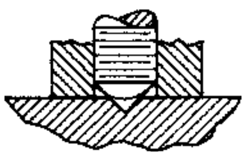


Fig. 23 Oval point.

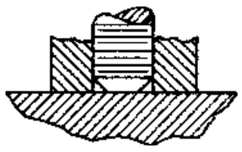


Fig. 24 Flat point.

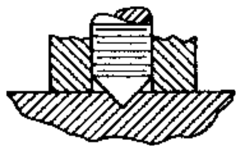


Fig. 25 Cone point.

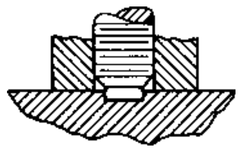


Fig. 26 Half-dog point.

The half-dog point should be considered in lieu of full-dog points when the usable length of thread is less than the nominal diameter. It is also more readily obtained than the full-dog point. It can be used in place of dowel pins and where end of thread must be protected (Fig. 26).

Lag Screws. Lag screws (Table 105) are usually used in wood but also can be used in plastics and with expansion shields in masonry. A 60° gimlet point is the most readily available type. A 60° cone point, not covered in these drawings, is also available. Some suppliers refer to this item as a lag bolt (Fig. 27).

A lag screw is normally used in wood when it is inconvenient or objectionable to use a through bolt and nut. To facilitate the insertion of the screw especially in denser types of wood, it is advisable to use a lubricant on the threads. It is important to have a pilot hole of proper size and following are some recommended hole sizes for commonly used types of wood. Hole sizes for other types of wood should be in proportion

Table 105 Lag Screws

Diameter of screw (in.)	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
No. of threads per inch	10	9	7	7	6	5	$4\frac{1}{2}$	4	$3\frac{1}{2}$
Across flats of hexagon and square heads (in.)	$\frac{3}{8}$	$\frac{15}{32}$	$\frac{9}{16}$	$\frac{21}{32}$	$\frac{3}{4}$	$\frac{15}{16}$	$1\frac{1}{8}$	$1\frac{5}{16}$	$1\frac{1}{2}$
Thickness of hexagon and square heads (in.)	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{17}{32}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$

Length of Threads for Screws of All Diameters

Length of screw (in.)	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	$4\frac{1}{2}$
Length of thread (in.)	To head	$1\frac{1}{2}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{1}{2}$
Length of screw (in.)	5	$5\frac{1}{2}$	6	7	8	9	10–12
Length of thread (in.)	4	4	$4\frac{1}{2}$	5	6	6	7

Table 106 Recommended Diameters of Pilot Hole for Types of Wood[a]

Screw Diameter (in.)	White Oak	Southern Yellow Pine, Douglas Fir	Redwood, Northern White Pine
0.250	0.160	0.150	0.100
0.312	0.210	0.195	0.132
0.375	0.260	0.250	0.180
0.438	0.320	0.290	0.228
0.500	0.375	0.340	0.280
0.625	0.485	0.437	0.375
0.750	0.600	0.540	0.480

[a] Pilot holes should be slightly larger than listed when lag screws of excessive lengths are to be used.

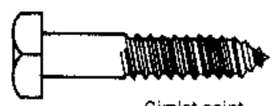


Fig. 27 Lag screws.

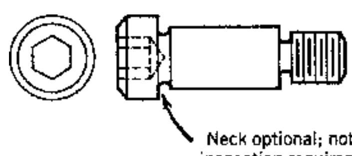


Fig. 28 Shoulder screw.

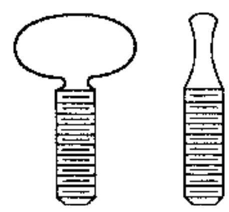


Fig. 29 Thumb screws.

to the relative specific gravity of that wood to the ones listed in Table 106.

Shoulder Screws. These screws are also referred to as "stripper bolts." They are used mainly as locators or retainers for spring strippers in punch and die operations and have found some application as fulcrums or pivots in machine designs that involve links, levers, or other oscillating parts. Consideration should be given to the alternative use of a sleeve bearing and a bolt on the basis of both cost and good design (Fig. 28).

Thumb Screws. Thumb screws have a flattened head designed for manual turning without a driver or a wrench. They are useful in applications requiring frequent disassembly or screw adjustment (Fig. 29).

Weld Screws. Weld screws come in many different head configurations, all designed to provide one or more projections for welding the screw to a part. Overhead projections are welded directly to the part. Underhead projections go through a pilot hole. The designs in Figs. 30 and 31 are widely used.

In projection welding of carbon steel screws, care should be observed in applications, since optimum weldability is obtained when the sum, for either parent metal or screw, of one-fourth the manganese content

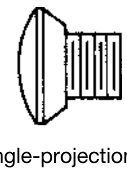


Fig. 30 Single-projection weld screw.

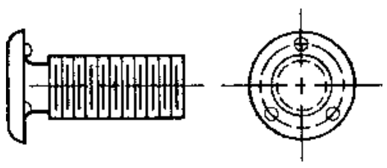


Fig. 31 Underhead weld screws.

plus the carbon content does not exceed 0.38. For good weldability with the annular ring type, the height of the weld projection should not exceed half the parent metal thickness as a rule of thumb.

Copper flash plating is provided for applications where cleanliness of the screw head is necessary in obtaining good welds.

Wood Screws. Wood screws are (Table 107) readily available in lengths from $\frac{1}{4}$ to 5 in. for steel and from $\frac{1}{4}$ to $3\frac{1}{2}$ in. for brass. Consideration should be given to the use of type AB thread-forming screws, which are lower in cost and more efficient than wood screws for use in wood. Wood screws are made with flat, round, or oval heads.

The *resistance of wood screws to withdrawal* from side grain of seasoned wood is given by the formula $P = 2850G^2D$, where P is the allowable load on the screw (lb/in. penetration of the threaded portion), G is specific gravity of oven-dry wood, and D is the diameter of the screw (in.). Wood screws should not be designed to be loaded in withdrawal from the end grain.

The *allowable safe lateral resistance* of wood screws embedded seven diameters in the side grain of seasoned wood is given by the formula $P = KD^2$, where P is the lateral resistance per screw (lb), D is the diameter (in.), and K is 4000 for oak (red and white), 3960 for Douglas fir (coast region) and southern pine, and 3240 for cypress (southern) and Douglas fir (inland region).

The following rules should be observed: (a) The size of the lead hole in soft (hard) woods should be about 70% (90%) of the core or root diameter of the screw; (b) lubricants such as soap may be used without great loss in holding power; (c) long, slender screws are preferable generally, but in hardwood too slender screws may reach the limit of their tensile strength; and (d) in the screws themselves, holding power is favored by thin sharp threads, rough unpolished surface, full diameter under the head, and shallow slots.

SEMS. The machine and tapping screws can be purchased with washers or lock washers as an integral part of the purchased screws. When thus joined together, the part is known as a SEMS unit. The washer is assembled on a headed screw blank before the threads are rolled. The inside diameter of the washer is of a size that will permit free rotation and yet prevent disassembly from the screw after the threads are rolled. If these screws and washers were purchased separately, there would be an initial cost savings over the preassembled units. However, these preassembled units reduce installation time because only one hand is needed to position them, leaving the other hand free to hold the driving tool. The time required to assemble a loose washer is eliminated. In addition, these assemblies act to minimize installation errors and inspection time because the washer is in place, correctly oriented. Also the use of a single unit, rather than two separate parts, simplifies bookkeeping, handling, inventory, and other related operations.

7.1 Nominal and Minimum Dressed Sizes of American Standard Lumber

Table 108 applies to boards, dimensional lumber, and timbers. The thicknesses apply to all widths and all widths to all thicknesses.

Table 107 American Standard Wood Screws[a]

Number	0	1	2	3	4	5	6	7	8
Threads per inch	32	28	26	24	22	20	18	16	15
Diameter (in.)	0.060	0.073	0.086	0.099	0.112	0.125	0.138	0.151	0.164
Number	9	10	11	12	14	16	18	20	24
Threads per inch	14	13	12	11	10	9	8	8	7
Diameter (in.)	0.177	0.190	0.203	0.216	0.242	0.268	0.294	0.320	0.372

[a]Included angle of flathead = 82°; see Fig. 18.

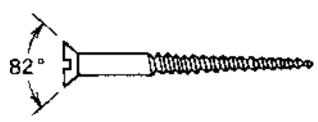


Table 108 Nominal and Minimum Dressed Sizes of American Standard Lumber

	Thicknesses			Face Widths		
		Minimum Dressed			Minimum Dressed	
Item	Nominal	Dry[a] (in.)	Green (in.)	Nominal	Dry[a] (in.)	Green (in.)
Boards[b]				2	$1\frac{1}{2}$	$1\frac{9}{16}$
				3	$2\frac{1}{2}$	$2\frac{9}{16}$
				4	$3\frac{1}{2}$	$3\frac{9}{16}$
				5	$4\frac{1}{2}$	$4\frac{5}{8}$
				6	$5\frac{1}{2}$	$5\frac{5}{8}$
	1	$\frac{3}{4}$	$\frac{25}{32}$	7	$6\frac{1}{2}$	$6\frac{5}{8}$
	$1\frac{1}{4}$	1	$1\frac{1}{32}$	8	$7\frac{1}{4}$	$7\frac{1}{2}$
	$1\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{9}{32}$	9	$8\frac{1}{4}$	$8\frac{1}{2}$
				10	$9\frac{1}{4}$	$9\frac{1}{2}$
				11	$10\frac{1}{4}$	$10\frac{1}{2}$
				12	$11\frac{1}{4}$	$11\frac{1}{2}$
				14	$13\frac{1}{4}$	$13\frac{1}{2}$
				16	$15\frac{1}{4}$	$15\frac{1}{2}$
Dimension				2	$1\frac{1}{2}$	$1\frac{9}{16}$
				3	$2\frac{1}{2}$	$2\frac{9}{16}$
				4	$3\frac{1}{2}$	$3\frac{9}{16}$
	2	$1\frac{1}{2}$	$1\frac{9}{16}$	5	$4\frac{1}{2}$	$4\frac{5}{8}$
	$2\frac{1}{2}$	2	$2\frac{1}{16}$	6	$5\frac{1}{2}$	$5\frac{5}{8}$
	3	$2\frac{1}{2}$	$2\frac{9}{16}$	8	$7\frac{1}{4}$	$7\frac{1}{2}$
	$3\frac{1}{2}$	3	$3\frac{1}{16}$	10	$9\frac{1}{4}$	$9\frac{1}{2}$
				12	$11\frac{1}{4}$	$11\frac{1}{2}$
				14	$13\frac{1}{4}$	$13\frac{1}{2}$
				16	$15\frac{1}{4}$	$15\frac{1}{2}$
Dimension				2	$1\frac{1}{2}$	$1\frac{9}{16}$
				3	$2\frac{1}{2}$	$2\frac{9}{16}$
				4	$3\frac{1}{2}$	$3\frac{9}{16}$
				5	$4\frac{1}{2}$	$4\frac{5}{8}$
	4	$3\frac{1}{2}$	$3\frac{9}{16}$	6	$5\frac{1}{2}$	$5\frac{5}{8}$
	$4\frac{1}{2}$	4	$4\frac{1}{16}$	8	$7\frac{1}{4}$	$7\frac{1}{2}$
				10	$9\frac{1}{4}$	$9\frac{1}{2}$
				12	$11\frac{1}{4}$	$11\frac{1}{2}$
				14		$13\frac{1}{2}$
				16		$15\frac{1}{2}$
Timbers	5 and thicker		$\frac{1}{2}$ off	5 and wider		$\frac{1}{2}$ off

[a]Maximum moisture content of 19 % or less.
[b]Boards less than the minimum thickness for 1 in. nominal but $\frac{5}{8}$ in. or greater thickness dry ($\frac{11}{16}$ in. green) may be regarded as American Standard Lumber, but such boards shall be marked to show the size and condition of seasoning at the time of dressing. They shall also be distinguished from 1-in. boards on invoices and certificates.
Source: From *American Softwood Lumber Standard*, NBS 20–70, National Bureau of Standards, Washington, DC, 1970, amended 1986 (available from Superintendent of Documents).