

Conversion Factors and Mathematical Symbols*

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* Much of the material was taken from Sec. 1. of the fifth edition. The contribution of Cecil H. Chilton in developing that material is acknowledged.

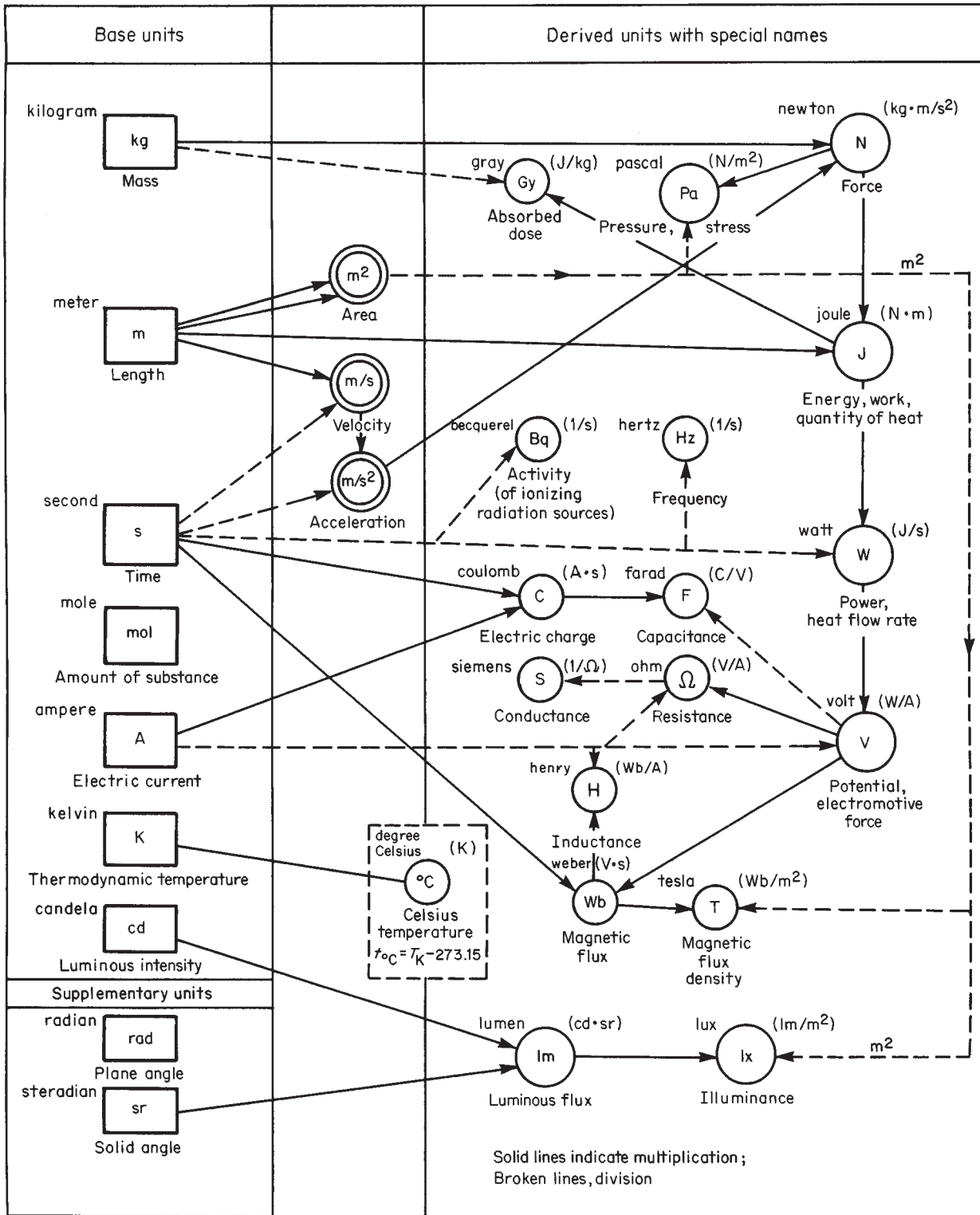


FIG. 1-1 Graphic relationships of SI units with names (U.S. National Bureau of Standards, LC 1078, December 1976.)

TABLE 1-1 SI Base and Supplementary Quantities and Units

Quantity or "dimension"	SI unit	SI unit symbol ("abbreviation"); Use roman (upright) type
Base quantity or "dimension"		
length	meter	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole*	mol
luminous intensity	candela	cd
Supplementary quantity or "dimension"		
plane angle	radian	rad
solid angle	steradian	sr

*When the mole is used, the elementary entities must be specified; they may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

TABLE 1-2a Derived Units of SI that Have Special Names

Quantity	Unit	Symbol	Formula
frequency (of a periodic phenomenon)	hertz	Hz	1/s
force	newton	N	(kg·m)/s ²
pressure, stress	pascal	Pa	N/m ²
energy, work, quantity of heat	joule	J	N·m
power, radiant flux	watt	W	J/s
quantity of electricity, electric charge	coulomb	C	A·s
electric potential, potential difference, electromotive force	volt	V	W/A
capacitance	farad	F	C/V
electric resistance	ohm	Ω	V/A
conductance	siemens	S	A/V
magnetic flux	weber	Wb	V·s
magnetic-flux density	tesla	T	Wb/m ²
inductance	henry	H	Wb/A
luminous flux	lumen	lm	cd·sr
illuminance	lux	lx	lm/m ²
activity (of radionuclides)	becquerel	Bq	1/s
absorbed dose	gray	Gy	J/kg

TABLE 1-2b Additional Common Derived Units of SI

Quantity	Unit	Symbol
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
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
heat capacity	joule per kelvin	J/K
heat-flux density, 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·K)
molar-heat capacity	joule per mole-kelvin	J/(mol·K)
moment of force	newton-meter	N·m
permeability	henry per meter	H/m
permittivity	farad per meter	F/m
radiance	watt per square-meter-steradian	W/(m ² ·sr)
radiant intensity	watt per steradian	W/sr
specific-heat capacity	joule per kilogram-kelvin	J/(kg·K)
specific energy	joule per kilogram	J/kg
specific entropy	joule per kilogram-kelvin	J/(kg·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·K)
velocity	meter per second	m/s
viscosity, dynamic	pascal-second	Pa·s
viscosity, kinematic	square meter per second	m ² /s
volume	cubic meter	m ³
wave number	1 per meter	1/m

TABLE 1-3 SI 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*	h
10 = 10 ¹	deka*	da
0.1 = 10 ⁻¹	deci*	d
0.01 = 10 ⁻²	centi	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

*Generally to be avoided.

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit	
Space, t time					
Length	naut mi	km		1.852°	E + 00
	mi	km		1.609 344°	E + 00
	chain	m		2.011 68°	E + 01
	link	m		2.011 68°	E - 01
	fathom	m		1.828 8°	E + 00
	yd	m		9.144°	E - 01
	ft	m		3.048°	E - 01
		cm		3.048°	E + 01
	in	mm		2.54°	E + 01
	in	cm		2.54	E + 00
mil	µm		2.54°	E + 01	
Length/length	ft/mi	m/km		1.893 939	E - 01
Length/volume	ft/U.S. gal	m/m ³		8.051 964	E + 01
	ft/ft ³	m/m ³		1.076 391	E + 01
	ft/bbl	m/m ³		1.917 134	E + 00
Area	mi ²	km ²		2.589 988	E + 00
	section	ha		2.589 988	E + 02
	acre	ha		4.046 856	E - 01
	ha	m ²		1.000 000°	E + 04
	yd ²	m ²		8.361 274	E - 01
	ft ²	m ²		9.290 304°	E - 02
	in ²	mm ²		6.451 6°	E + 02
		cm ²		6.451 6°	E + 00
Area/volume	ft ² /in ³	m ² /cm ³		5.699 291	E - 03
	ft ² /ft ³	m ² /m ³		3.280 840	E + 00
Volume	cubem	km ³		4.168 182	E + 00
	acre-ft	m ³		1.233 482	E + 03
		ha·m		1.233 482	E - 01
	yd ³	m ³		7.645 549	E - 01
	bbl (42 U.S. gal)	m ³		1.589 873	E - 01
	ft ³	m ³		2.831 685	E - 02
		dm ³	L	2.831 685	E + 01
	U.K. gal	m ³		4.546 092	E - 03
		dm ³	L	4.546 092	E + 00
	U.S. gal	m ³		3.785 412	E - 03
		dm ³	L	3.785 412	E + 00
	U.K. qt	dm ³	L	1.136 523	E + 00
	U.S. qt	dm ³	L	9.463 529	E - 01
	U.S. pt	dm ³	L	4.731 765	E - 01
	U.K. fl oz	cm ³		2.841 307	E + 01
	U.S. fl oz	cm ³		2.957 353	E + 01
in ³	cm ³		1.638 706	E + 01	
Volume/length (linear displacement)	bbl/in	m ³ /m		6.259 342	E + 00
	bbl/ft	m ³ /m		5.216 119	E - 01
	ft ³ /ft	m ³ /m		9.290 304°	E - 02
	U.S. gal/ft	m ³ /m		1.241 933	E - 02
	L/m		1.241 933	E + 01	
Plane angle	rad	rad		1	
	deg (°)	rad		1.745 329	E - 02
	min (')	rad		2.908 882	E - 04
	sec (")	rad		4.848 137	E - 06
Solid angle	sr	sr		1	
Time	year	a		1	
	week	d		7.0°	E + 00
	h	s		3.6°	E + 03
		min		6.0°	E + 01
	min	s		6.0°	E + 01
		h		1.666 667	E - 02
	mµs	ns		1	
Mass, amount of substance					
Mass	U.K. ton	Mg	t	1.016 047	E + 00
	U.S. ton	Mg	t	9.071 847	E - 01
	U.K. cwt	kg		5.080 234	E + 01
	U.S. cwt	kg		4.535 924	E + 01
	lbm	kg		4.535 924	E - 01
	oz (troy)	g		3.110 348	E + 01
	oz (av)	g		2.834 952	E + 01
	gr	mg		6.479 891	E + 01

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TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units (Continued)

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
Amount of substance	lbm·mol	kmol		4.535 924 E - 01
	std m ³ (0°C, 1 atm)	kmol		4.461 58 E - 02
	std ft ³ (60°F, 1 atm)	kmol		1.195 30 E - 03
Enthalpy, calorific value, heat, entropy, heat capacity				
Calorific value, enthalpy (mass basis)	Btu/lbm	MJ/kg	J/g	2.326 000 E - 03
		kJ/kg		2.326 000 E + 00
	cal/g cal/lbm	kWh/kg	J/g	6.461 112 E - 04
		kJ/kg J/kg		4.184° E + 00 9.224 141 E + 00
Caloric value, enthalpy (mole basis)	kcal/(g·mol)	kJ/kmol		4.184° E + 03
	Btu/(lb·mol)	kJ/kmol		2.326 000 E + 00
Calorific value (volume basis—solids and liquids)	Btu/U.S. gal	MJ/m ³	kJ/dm ³	2.787 163 E - 01
		kJ/m ³		2.787 163 E + 02
		kWh/m ³		7.742 119 E - 02
	Btu/U.K. gal	MJ/m ³	kJ/dm ³	2.320 800 E - 01
		kJ/m ³		2.320 800 E + 02
	Btu/ft ³	kWh/m ³	kJ/dm ³	6.446 667 E - 02
		MJ/m ³		3.725 895 E - 02
		kJ/m ³		3.725 895 E + 01
		kWh/m ³		1.034 971 E - 02
	cal/mL (ft·lbf)/U.S. gal	MJ/m ³		4.184° E + 00
kJ/m ³			3.581 692 E - 01	
Calorific value (volume basis—gases)	cal/mL	kJ/m ³	J/dm ³	4.184° E + 03
	kcal/m ³	kJ/m ³	J/dm ³	4.184° E + 00
	Btu/ft ³	kJ/m ³	J/dm ³	3.725 895 E + 01
		kWh/m ³		1.034 971 E - 02
Specific entropy	Btu/(lbm·°R)	kJ/(kg·K)	J/(g·K)	4.186 8° E + 00
	cal/(g·K)	kJ/(kg·K)	J/(g·K)	4.184° E + 00
	kcal/(kg·°C)	kJ/(kg·K)	J/(g·K)	4.184° E + 00
Specific-heat capacity (mass basis)	kWh/(kg·°C)	kJ/(kg·K)	J/(g·K)	3.6° E + 03
	Btu/(lbm·°F)	kJ/(kg·K)	J/(g·K)	4.186 8° E + 00
	kcal/(kg·°C)	kJ/(kg·K)	J/(g·K)	4.184° E + 00
Specific-heat capacity (mole basis)	Btu/(lb·mol·°F)	kJ/(kmol·K)		4.186 8° E + 00
	cal/(g·mol·°C)	kJ/(kmol·K)		4.184° E + 00
Temperature, pressure, vacuum				
Temperature (absolute)	°R	K		5/9
	K	K		1
Temperature (traditional)	°F	°C		5/9(°F - 32)
Temperature (difference)	°F	K, °C		5/9
Pressure	atm (760 mmHg at 0°C or 14,696 psi)	MPa		1.013 250° E - 01
		kPa		1.013 250° E + 02
		bar		1.013 250° E + 00
	bar	MPa		1.0° E - 01
		kPa		1.0° E + 02
		MPa		6.894 757 E - 03
	mmHg (0°C) = torr	kPa		6.894 757 E + 00
		bar		6.894 757 E - 02
		kPa		3.376 85 E + 00
	μmHg (0°C)	kPa		2.488 4 E - 01
	μ bar	kPa		1.333 224 E - 01
	mmHg = torr (0°C)	kPa		9.806 38 E - 02
	cmH ₂ O (4°C)	kPa		9.806 38 E - 02
	lb/ft ² (psf)	kPa		4.788 026 E - 02
	mHg (0°C)	Pa		1.333 224 E - 01
bar	Pa		1.0° E + 05	
dyn/cm ²	Pa		1.0° E - 01	
Vacuum, draft	inHg (60°F)	kPa		3.376 85 E + 00
	inH ₂ O (39.2°F)	kPa		2.490 82 E - 01
	inH ₂ O (60°F)	kPa		2.488 4 E - 01
	mmHg (0°C) = torr	kPa		1.333 224 E - 01
	cmH ₂ O (4°C)	kPa		9.806 38 E - 02
Liquid head	ft	m		3.048° E - 01
	in	mm		2.54° E + 01
		cm		2.54° E + 00
Pressure drop/length	psi/ft	kPa/m		2.262 059 E + 01

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units (Continued)

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit		
Density, specific volume, concentration, dosage						
Density	lbm/ft ³	kg/m ³		1.601 846	E + 01	
		g/m ³		1.601 846	E + 04	
	lbm/U.S. gal	kg/m ³		1.198 264	E + 02	
		g/cm ³		1.198 264	E - 01	
	lbm/U.K. gal	kg/m ³		9.977 633	E + 01	
	lbm/ft ³	kg/m ³		1.601 846	E + 01	
	g/cm ³	g/cm ³		1.601 846	E - 02	
	lbm/ft ³	kg/m ³		1.0*	E + 03	
		kg/m ³		1.601 846	E + 01	
Specific volume	ft ³ /lbm	m ³ /kg		6.242 796	E - 02	
		m ³ /g		6.242 796	E - 05	
	ft ³ /lbm	dm ³ /kg		6.242 796	E + 01	
	U.K. gal/lbm	dm ³ /kg	cm ³ /g	1.002 242	E + 01	
	U.S. gal/lbm	dm ³ /kg	cm ³ /g	8.345 404	E + 00	
Specific volume (mole basis)	L/(g·mol)	m ³ /kmol		1		
	ft ³ /(lb·mol)	m ³ /kmol		6.242 796	E - 02	
Specific volume	bbl/U.S. ton	m ³ /t		1.752 535	E - 01	
	bbl/U.K. ton	m ³ /t		1.564 763	E - 01	
Yield	bbl/U.S. ton	dm ³ /t	L/t	1.752 535	E + 02	
	bbl/U.K. ton	dm ³ /t	L/t	1.564 763	E + 02	
	U.S. gal/U.S. ton	dm ³ /t	L/t	4.172 702	E + 00	
	U.S. gal/U.K. ton	dm ³ /t	L/t	3.725 627	E + 00	
Concentration (mass/mass)	wt %	kg/kg		1.0*	E - 02	
		g/kg		1.0*	E + 01	
	wt ppm	mg/kg		1		
Concentration (mass/volume)	lbm/bbl	kg/m ³	g/dm ³	2.853 010	E + 00	
	g/U.S. gal	kg/m ³		2.641 720	E - 01	
	g/U.K. gal	kg/m ³	g/L	2.199 692	E - 01	
	lbm/1000 U.S. gal	g/m ³	mg/dm ³	1.198 264	E + 02	
	lbm/1000 U.K. gal	g/m ³	mg/dm ³	9.977 633	E + 01	
	gr/U.S. gal	g/m ³	mg/dm ³	1.711 806	E + 01	
	gr/ft ³	mg/m ³		2.288 351	E + 03	
	lbm/1000 bbl	g/m ³	mg/dm ³	2.853 010	E + 00	
	mg/U.S. gal	g/m ³	mg/dm ³	2.641 720	E - 01	
	gr/100 ft ³	mg/m ³		2.288 351	E + 01	
	Concentration (volume/volume)	ft ³ /ft ³	m ³ /m ³		1	
bbl/(acre-ft)		m ³ /m ³		1.288 931	E - 04	
vol%		m ³ /m ³		1.0*	E - 02	
U.K. gal/ft ³		dm ³ /m ³	L/m ³	1.605 437	E + 02	
U.S. gal/ft ³		dm ³ /m ³	L/m ³	1.336 806	E + 02	
mL/U.S. gal		dm ³ /m ³	L/m ³	2.641 720	E - 01	
mL/U.K. gal		dm ³ /m ³	L/m ³	2.199 692	E - 01	
vol ppm		cm ³ /m ³		1		
		dm ³ /m ³	L/m ³	1.0*	E - 03	
U.K. gal/1000 bbl		cm ³ /m ³		2.859 403	E + 01	
U.S. gal/1000 bbl		cm ³ /m ³		2.380 952	E + 01	
U.K. pt/1000 bbl		cm ³ /m ³		3.574 253	E + 00	
Concentration (mole/volume)		(lb·mol)/U.S. gal	kmol/m ³		1.198 264	E + 02
		(lb·mol)/U.K. gal	kmol/m ³		9.977 644	E + 01
	(lb·mol)/ft ³	kmol/m ³		1.601 846	E + 01	
	std ft ³ (60°F, 1 atm)/bbl	kmol/m ³		7.518 21	E - 03	
Concentration (volume/mole)	U.S. gal/1000 std ft ³ (60°F/60°F)	dm ³ /kmol	L/kmol	3.166 91	E + 00	
	bbl/million std ft ³ (60°F/60°F)	dm ³ /kmol	L/kmol	1.330 10	E - 01	
Facility throughput, capacity						
Throughput (mass basis)	U.K. ton/year	t/a		1.016 047	E + 00	
	U.S. ton/year	t/a		9.071 847	E - 01	
	U.K. ton/day	t/d		1.016 047	E + 00	
		t/h		4.233 529	E - 02	
	U.S. ton/day	t/d		9.071 847	E - 01	
		t/h		3.779 936	E - 02	
	U.K. ton/h	t/h		1.016 047	E + 00	
	U.S. ton/h	t/h		9.071 847	E - 01	
	lbm/h	kg/h		4.535 924	E - 01	

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units (Continued)

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
Throughput (volume basis)	bb/day	t/a		5.803 036 E + 01
		m ³ /d		1.589 873 E - 01
	ft ³ /day	m ³ /h		1.179 869 E - 03
	bb/h	m ³ /h		1.589 873 E - 01
	ft ³ /h	m ³ /h		2.831 685 E - 02
	U.K. gal/h	m ³ /h		4.546 092 E - 03
		L/s		1.262 803 E - 03
	U.S. gal/h	m ³ /h		3.785 412 E - 03
		L/s		1.051 503 E - 03
	U.K. gal/min	m ³ /h		2.727 655 E - 01
		L/s		7.576 819 E - 02
	U.S. gal/min	m ³ /h		2.271 247 E - 01
	L/s		6.309 020 E - 02	
Throughput (mole basis)	(lbm-mol)/h	kmol/h		4.535 924 E - 01
		kmol/s		1.259 979 E - 04
Flow rate				
Flow rate (mass basis)	U.K. ton/min	kg/s		1.693 412 E + 01
	U.S. ton/min	kg/s		1.511 974 E + 01
	U.K. ton/h	kg/s		2.822 353 E - 01
	U.S. ton/h	kg/s		2.519 958 E - 01
	U.K. ton/day	kg/s		1.175 980 E - 02
	U.S. ton/day	kg/s		1.049 982 E - 02
	million lbm/year	kg/s		5.249 912 E + 00
	U.K. ton/year	kg/s		3.221 864 E - 05
	U.S. ton/year	kg/s		2.876 664 E - 05
	lbm/s	kg/s		4.535 924 E - 01
	lbm/min	kg/s		7.559 873 E - 03
	lbm/h	kg/s		1.259 979 E - 04
Flow rate (volume basis)	bb/day	m ³ /d		1.589 873 E - 01
		L/s		1.840 131 E - 03
	ft ³ /day	m ³ /d		2.831 685 E - 02
		L/s		3.277 413 E - 04
	bb/h	m ³ /s		4.416 314 E - 05
		L/s		4.416 314 E - 02
	ft ³ /h	m ³ /s		7.865 791 E - 06
		L/s		7.865 791 E - 03
	U.K. gal/h	dm ³ /s	L/s	1.262 803 E - 03
	U.S. gal/h	dm ³ /s	L/s	1.051 503 E - 03
	U.K. gal/min	dm ³ /s	L/s	7.576 820 E - 02
	U.S. gal/min	dm ³ /s	L/s	6.309 020 E - 02
	ft ³ /min	dm ³ /s	L/s	4.719 474 E - 01
	ft ³ /s	dm ³ /s	L/s	2.831 685 E + 01
Flow rate (mole basis)	(lb-mol)/s	kmol/s		4.535 924 E - 01
	(lb-mol)/h	kmol/s		1.259 979 E - 04
	million scf/D	kmol/s		1.383 45 E - 02
Flow rate/length (mass basis)	lbm/(s-ft)	kg/(s-m)		1.488 164 E + 00
	lbm/(h-ft)	kg/(s-m)		4.133 789 E - 04
Flow rate/length (volume basis)	U.K. gal/(min-ft)	m ³ /s	m ³ /(s-m)	2.485 833 E - 04
	U.S. gal/(min-ft)	m ³ /s	m ³ /(s-m)	2.069 888 E - 04
	U.K. gal/(h-in)	m ³ /s	m ³ /(s-m)	4.971 667 E - 05
	U.S. gal/(h-in)	m ³ /s	m ³ /(s-m)	4.139 776 E - 05
	U.K. gal/(h-ft)	m ³ /s	m ³ /(s-m)	4.143 055 E - 06
	U.S. gal/(h-ft)	m ³ /s	m ³ /(s-m)	3.449 814 E - 06
Flow rate/area (mass basis)	lbm/(s-ft ²)	kg/(s-m ²)		4.882 428 E + 00
	lbm/(h-ft ²)	kg/(s-m ²)		1.356 230 E - 03
Flow rate/area (volume basis)	ft ³ /(s-ft ²)	m/s	m ³ /(s-m ²)	3.048° E - 01
	ft ³ /(min-ft ²)	m/s	m ³ /(s-m ²)	5.08° E - 03
	U.K. gal/(h-in ²)	m/s	m ³ /(s-m ²)	1.957 349 E - 03
	U.S. gal/(h-in ²)	m/s	m ³ /(s-m ²)	1.629 833 E - 03
	U.K. gal/(min-ft ²)	m/s	m ³ /(s-m ²)	8.155 621 E - 04
	U.S. gal/(min-ft ²)	m/s	m ³ /(s-m ²)	6.790 972 E - 04
	U.K. gal/(h-ft ²)	m/s	m ³ /(s-m ²)	1.359 270 E - 05
	U.S. gal/(h-ft ²)	m/s	m ³ /(s-m ²)	1.131 829 E - 05

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units (Continued)

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
Energy, work, power				
Energy, work	therm	MJ		1.055 056 E + 02
		kJ		1.055 056 E + 05
		kWh		2.930 711 E + 01
	U.S. tonf-mi	MJ		1.431 744 E + 01
		MJ		2.684 520 E + 00
		kJ		2.684 520 E + 03
	hp-h	kWh		7.456 999 E - 01
		MJ		2.647 780 E + 00
		kJ		2.647 780 E + 03
	ch-h or CV-h	kWh		7.354 999 E - 01
		MJ		3.6° E + 00
		kJ		3.6° E + 03
	kWh	MJ		1.899 101 E + 00
		kJ		5.275 280 E - 04
	Chu	kWh		1.055 056 E + 00
		MJ		2.930 711 E - 04
	Btu	kJ		4.184° E + 00
		kWh		4.184° E - 03
	kcal	kJ		1.355 818 E - 03
		cal		1.355 818 E - 03
ft-lbf	kJ		1.0° E - 03	
	lbf-ft		4.214 011 E - 05	
J	kJ		1.0° E - 07	
	(lbf-ft ²)/s ²			
erg	J			
Impact energy	kgf-m	J		9.806 650° E + 00
	lbf-ft	J		1.355 818 E + 00
Surface energy	erg/cm ²	mJ/m ²		1.0° E + 00
Specific-impact energy	(kgf-m)/cm ²	J/cm ²		9.806 650° E - 02
	(lbf-ft)/in ²	J/cm ²		2.101 522 E - 03
Power	million Btu/h	MW		2.930 711 E - 01
	ton of refrigeration	kW		3.516 853 E + 00
	Btu/s	kW		1.055 056 E + 00
	kW	kW		1
	hydraulic horsepower—hhp	kW		7.460 43 E - 01
	hp (electric)	kW		7.46° E - 01
	hp [(550 ft-lbf)/s]	kW		7.456 999 E - 01
	ch or CV	kW		7.354 999 E - 01
	Btu/min	kW		1.758 427 E - 02
	(ft-lbf)/s	kW		1.355 818 E - 03
	kcal/h	W		1.162 222 E + 00
	Btu/h	W		2.930 711 E - 01
	(ft-lbf)/min	W		2.259 697 E - 02
	Power/area	Btu/(s-ft ²)	kW/m ²	
cal/(h-cm ²)		kW/m ²		1.162 222 E - 02
Btu/(h-ft ²)		kW/m ²		3.154 591 E - 03
Heat-release rate, mixing power	hp/ft ³	kW/m ³		2.633 414 E + 01
	cal/(h-cm ³)	kW/m ³		1.162 222 E + 00
	Btu/(s-ft ³)	kW/m ³		3.725 895 E + 01
	Btu/(h-ft ³)	kW/m ³		1.034 971 E - 02
Cooling duty (machinery)	Btu/(bhp-h)	W/kW		3.930 148 E - 01
Specific fuel consumption (mass basis)	lbm/(hp-h)	mg/J	kg/MJ	1.689 659 E - 01
		kg/kWh		6.082 774 E - 01
Specific fuel consumption (volume basis)	m ³ /kWh	dm ³ /MJ	mm ³ /J	2.777 778 E + 02
	U.S. gal/(hp-h)	dm ³ /MJ	mm ³ /J	1.410 089 E + 00
	U.K. pt/(hp-h)	dm ³ /MJ	mm ³ /J	2.116 806 E - 01
Fuel consumption	U.K. gal/mi	dm ³ /100 km	L/100 km	2.824 807 E + 02
	U.S. gal/mi	dm ³ /100 km	L/100 km	2.352 146 E + 02
	mi/U.S. gal	km/dm ³	km/L	4.251 437 E - 01
	mi/U.K. gal	km/dm ³	km/L	3.540 064 E - 01

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units (Continued)

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit	
Velocity (linear), speed	knot	km/h		1.852°	E + 00
	mi/h	km/h		1.609 344°	E + 00
	ft/s	m/s		3.048°	E - 01
		cm/s		3.048°	E + 01
	ft/min	m/s		5.08°	E - 03
	ft/h	mm/s		8.466 667	E - 02
	ft/day	mm/s		3.527 778	E - 03
		m/d		3.048°	E - 01
Corrosion rate	in/year (ipy)	mm/a		2.54°	E + 01
	mil/year	mm/a		2.54°	E - 02
Rotational frequency	r/min	r/s		1.666 667	E - 02
		rad/s		1.047 198	E - 01
Acceleration (linear)	ft/s ²	m/s ²		3.048°	E - 01
		cm/s ²		3.048°	E + 01
Acceleration (rotational)	rpm/s	rad/s ²		1.047 198	E - 01
Momentum	(lbm-ft)/s	(kg-m)/s		1.382 550	E - 01
Force	U.K. tonf	kN		9.964 016	E + 00
	U.S. tonf	kN		8.896 443	E + 00
	kgf (kp)	N		9.806 650°	E + 00
	lbf	N		4.448 222	E + 00
	dyn	mN		1.0	E - 02
Bending moment, torque	U.S. tonf-ft	kN-m		2.711 636	E + 00
	kgf-m	N-m		9.806 650°	E + 00
	lbf-ft	N-m		1.355 818	E + 00
	lbf-in	N-m		1.129 848	E - 01
Bending moment/length	(lbf-ft)/in	(N-m)/m		5.337 866	E + 01
	(lbf-in)/in	(N-m)/m		4.448 222	E + 00
Moment of inertia	lbm-ft ²	kg-m ²		4.214 011	E - 02
Stress	U.S. tonf/in ²	MPa	N/mm ²	1.378 951	E + 01
	kgf/mm ²	MPa	N/mm ²	9.806 650°	E + 00
	U.S. tonf/ft ²	MPa	N/mm ²	9.576 052	E - 02
	lbf/in ² (psi)	MPa	N/mm ²	6.894 757	E - 03
	lbf/ft ² (psf)	kPa		4.788 026	E - 02
	dyn/cm ²	Pa		1.0°	E - 01
Mass/length	lbm/ft	kg/m		1.488 164	E + 00
Mass/area structural loading, bearing capacity (mass basis)	U.S. ton/ft ²	Mg/m ²		9.764 855	E + 00
	lbm/ft ²	kg/m ²		4.882 428	E + 00
Miscellaneous transport properties					
Diffusivity	ft ² /s	m ² /s		9.290 304°	E - 02
	m ² /s	mm ² /s		1.0°	E + 06
	ft ² /h	m ² /s		2.580 64°	E - 05
Thermal resistance	(°C-m ² -h)/kcal	(K-m ²)/kW		8.604 208	E + 02
	(°F-ft ² -h)/Btu	(K-m ²)/kW		1.761 102	E + 02
Heat flux	Btu/(h-ft ²)	kW/m ²		3.154 591	E - 03
Thermal conductivity	(cal-cm)/(s-cm ² -°C)	W/(m-K)		4.184°	E + 02
	(Btu-ft)/(h-ft ² -°F)	W/(m-K)		1.730 735	E + 00
		(kJ-m)/(h-m ² -K)		6.230 646	E + 00
	(kcal-m)/(h-m ² -°C)	W/(m-K)		1.162 222	E + 00
	(Btu-in)/(h-ft ² -°F)	W/(m-K)		1.442 279	E - 01
	(cal-cm)/(h-cm ² -°C)	W/(m-K)		1.162 222	E - 01
Heat-transfer coefficient	cal/(s-cm ² -°C)	kW/(m ² -K)		4.184°	E + 01
	Btu/(s-ft ² -°F)	kW/(m ² -K)		2.044 175	E + 01
	cal/(h-cm ² -°C)	kW/(m ² -K)		1.162 222	E - 02
	Btu/(h-ft ² -°F)	kW/(m ² -K)		5.678 263	E - 03
		kJ/(h-m ² -K)		2.044 175	E + 01
	Btu/(h-ft ² -°R)	kW/(m ² -K)		5.678 263	E - 03
	kcal/(h-m ² -°C)	kW/(m ² -K)		1.162 222	E - 03

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units (Continued)

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit
Volumetric heat-transfer coefficient	Btu/(s·ft ³ ·°F)	kW/(m ³ ·K)		6.706 611 E + 01
	Btu/(h·ft ³ ·°F)	kW/(m ³ ·K)		1.862 947 E - 02
Surface tension	dyn/cm	mN/m		1
Viscosity (dynamic)	(lbf·s)/in ²	Pa·s	(N·s)/m ²	6.894 757 E + 03
	(lbf·s)/ft ²	Pa·s	(N·s)/m ²	4.788 026 E + 01
	(kgf·s)/m ²	Pa·s	(N·s)/m ²	9.806 650° E + 00
	lbm/(ft·s)	Pa·s	(N·s)/m ²	1.488 164 E + 00
	(dyn·s)/cm ²	Pa·s	(N·s)/m ²	1.0° E - 01
	cP	Pa·s	(N·s)/m ²	1.0° E - 03
	lbm/(ft·h)	Pa·s	(N·s)/m ²	4.133 789 E - 04
Viscosity (kinematic)	ft ² /s	m ² /s		9.290 304° E - 02
	in ² /s	mm ² /s		6.451 6° E + 02
	m ² /h	mm ² /s		2.777 778 E + 02
	ft ² /h	m ² /s		2.580 64° E - 05
	cSt	mm ² /s		1
Permeability	darcy	μm ²		9.869 233 E - 01
	millidarcy	μm ²		9.869 233 E - 04
Thermal flux	Btu/(h·ft ²)	W/m ²		3.152 E + 00
	Btu/(s·ft ²)	W/m ²		1.135 E + 04
	cal/(s·cm ²)	W/m ²		4.184 E + 04
Mass-transfer coefficient	(lb·mol)/[h·ft ² (lb·mol/ft ³)]	m/s		8.467 E - 05
	(g·mol)/[s·m ² (g·mol/L)]	m/s		1.0 E + 01
Electricity, magnetism				
Admittance	S	S		1
Capacitance	μF	μF		1
Charge density	C/mm ³	C/mm ³		1
Conductance	S	S		1
	Ū (mho)	S		1
Conductivity	S/m	S/m		1
	Ū/m	S/m		1
	mŪ/m	mS/m		1
Current density	A/mm ²	A/mm ²		1
Displacement	C/cm ²	C/cm ²		1
Electric charge	C	C		1
Electric current	A	A		1
Electric-dipole moment	C·m	C·m		1
Electric-field strength	V/m	V/m		1
Electric flux	C	C		1
Electric polarization	C/cm ²	C/cm ²		1
Electric potential	V	V		1
	mV	mV		1
Electromagnetic moment	A·m ²	A·m ²		1
Electromotive force	V	V		1
Flux of displacement	C	C		1
Frequency	cycles/s	Hz		1
Impedance	Ω	Ω		1
Linear-current density	A/mm	A/mm		1
Magnetic-dipole moment	Wb·m	Wb·m		1
Magnetic-field strength	A/mm	A/mm		1
	Oe	A/m		7.957 747 E + 01
	gamma	A/m		7.957 747 E - 04
Magnetic flux	mWb	mWb		1

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units (Continued)

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit	
Magnetic-flux density	mT	mT		1	
	G	T		1.0*	E - 04
	gamma	nT		1	
Magnetic induction	mT	mT		1	
Magnetic moment	A·m ²	A·m ²		1	
Magnetic polarization	mT	mT		1	
Magnetic potential difference	A	A		1	
Magnetic-vector potential	Wb/mm	Wb/mm		1	
Magnetization	A/mm	A/mm		1	
Modulus of admittance	S	S		1	
Modulus of impedance	Ω	Ω		1	
Mutual inductance	H	H		1	
Permeability	μH/m	μH/m		1	
Permeance	H	H		1	
Permittivity	μF/m	μF/m		1	
Potential difference	V	V		1	
Quantity of electricity	C	C		1	
Reactance	Ω	Ω		1	
Reluctance	H ⁻¹	H ⁻¹		1	
Resistance	Ω	Ω		1	
Resistivity	Ω·cm	Ω·cm		1	
	Ω·m	Ω·m		1	
Self-inductance	mH	mH		1	
Surface density of charge	mC/m ²	mC/m ²		1	
Susceptance	S	S		1	
Volume density of charge	C/mm ³	C/mm ³		1	
Acoustics, light, radiation					
Absorbed dose	rad	Gy		1.0*	E - 02
Acoustical energy	J	J		1	
Acoustical intensity	W/cm ²	W/m ²		1.0*	E + 04
Acoustical power	W	W		1	
Sound pressure	N/m ²	N/m ²		1.0*	
Illuminance	fc	lx		1.076 391	E + 01
Illumination	fc	lx		1.076 391	E + 01
Irradiance	W/m ²	W/m ²		1	
Light exposure	fc·s	lx·s		1.076 391	E + 01
Luminance	cd/m ²	cd/m ²		1	
Luminous efficacy	lm/W	lm/W		1	
Luminous exitance	lm/m ²	lm/m ²		1	
Luminous flux	lm	lm		1	
Luminous intensity	cd	cd		1	
Radiance	W/m ² ·sr	W/m ² ·sr		1	
Radiant energy	J	J		1	
Radiant flux	W	W		1	
Radiant intensity	W/sr	W/sr		1	
Radiant power	W	W		1	

TABLE 1-4 Conversion Factors: U.S. Customary and Commonly Used Units to SI Units (Concluded)

Quantity	Customary or commonly used unit	SI unit	Alternate SI unit	Conversion factor; multiply customary unit by factor to obtain SI unit	
Wavelength	Å	nm		1.0*	E - 01
Capture unit	10 ⁻³ cm ⁻¹	m ⁻¹		1.0*	E + 01
	m ⁻¹	m ⁻¹	10 ⁻³ cm ⁻¹	1	1
Radioactivity	Ci	Bq		3.7*	E + 10

* An asterisk indicates that the conversion factor is exact.

† Conversion factors for length, area, and volume are based on the international foot. The international foot is longer by 2 parts in 1 million than the U.S. Survey foot (land-measurement use).

NOTE: The following unit symbols are used in the table:

Unit symbol	Name	Unit symbol	Name
A	ampere	lm	lumen
a	annum (year)	lx	lux
Bq	becquerel	m	meter
C	coulomb	min	minute
cd	candela	'	minute
Ci	curie	N	newton
d	day	naut mi	U.S. nautical mile
°C	degree Celsius	Oe	oersted
°	degree	Ω	ohm
dyn	dyne	Pa	pascal
F	farad	rad	radian
fc	footcandle	r	revolution
G	gauss	S	siemens
g	gram	s	second
gr	grain	"	second
Gy	gray	sr	steradian
H	henry	St	stokes
h	hour	T	tesla
ha	hectare	t	tonne
Hz	hertz	V	volt
J	joule	W	watt
K	kelvin	Wb	weber
L, ℓ, l	liter		

NOTE: Copyright SPE-AIME, *The SI Metric System of Units and SPE's Tentative Metric Standard*, Society of Petroleum Engineers, Dallas, 1977.

TABLE 1-5 Metric Conversion Factors as Exact Numerical Multiples of SI Units

The first two digits of each numerical entry represent a power of 10. For example, the entry “-02 2.54” expresses the fact that 1 in = 2.54×10^{-2} m.

To convert from	To	Multiply by	To convert from	To	Multiply by
abampere	ampere	+01 1.00	fluid ounce (U.S.)	meter ³	-05 2.957 352
abcoulomb	coulomb	+01 1.00	foot	meter	-01 3.048
abfarad	farad	+09 1.00	foot (U.S. survey)	meter	-01 3.048 006
abhenry	henry	-09 1.00	foot of water (39.2°F)	newton/meter ²	+03 2.988 98
abmho	mho	+09 1.00	footcandle	lumen/meter ²	+01 1.076 391
abohm	ohm	-09 1.00	footlambert	candela/meter ²	+00 3.426 259
abvolt	volt	-08 1.00	furlong	meter	+02 2.011 68
acre	meter ²	+03 4.046 856	gal (galileo)	meter/second ²	-02 1.00
ampere (international of 1948)	ampere	-01 9.998 35	gallon (U.K. liquid)	meter ³	-03 4.546 087
angstrom	meter	-10 1.00	gallon (U.S. dry)	meter ³	-03 4.404 883
are	meter ²	+02 1.00	gallon (U.S. liquid)	meter ³	-03 3.785 411
astronomical unit	meter	+11 1.495 978	gamma	tesla	-09 1.00
atmosphere	newton/meter ²	+05 1.013 25	gauss	tesla	-04 1.00
bar	newton/meter ²	+05 1.00	gilbert	ampere turn	-01 7.957 747
barn	meter ²	-28 1.00	gill (U.K.)	meter ³	-04 1.420 652
barrel (petroleum 42 gal)	meter ³	-01 1.589 873	gill (U.S.)	meter ³	-04 1.182 941
barye	newton/meter ²	-01 1.00	grad	degree (angular)	-01 9.00
British thermal unit (ISO/TC 12)	joule	+03 1.055 06	grad	radian	-02 1.570 796
British thermal unit (International Steam Table)	joule	+03 1.055 04	grain	kilogram	-05 6.479 891
British thermal unit (mean)	joule	+03 1.055 87	gram	kilogram	-03 1.00
British thermal unit (thermochemical)	joule	+03 1.054 350	hand	meter	-01 1.016
British thermal unit (39°F)	joule	+03 1.059 67	hectare	meter ²	+04 1.00
British thermal unit (60°F)	joule	+03 1.054 68	henry (international of 1948)	henry	+00 1.000 495
bushel (U.S.)	meter ³	-02 3.523 907	hogshead (U.S.)	meter ³	-01 2.384 809
cable	meter	+02 2.194 56	horsepower (550 ft lbf/s)	watt	+02 7.456 998
caliber	meter	-04 2.54	horsepower (boiler)	watt	+03 9.809 50
calorie (International Steam Table)	joule	+00 4.1868	horsepower (electric)	watt	+02 7.46
calorie (mean)	joule	+00 4.190 02	horsepower (metric)	watt	+02 7.354 99
calorie (thermochemical)	joule	+00 4.184	horsepower (U.K.)	watt	+02 7.457
calorie (15°C)	joule	+00 4.185 80	horsepower (water)	watt	+02 7.460 43
calorie (20°C)	joule	+00 4.181 90	hour (mean solar)	second (mean solar)	+03 3.60
calorie (kilogram, International Steam Table)	joule	+03 4.186 8	hour (sidereal)	second (mean solar)	+03 3.590 170
calorie (kilogram, mean)	joule	+03 4.190 02	hundredweight (long)	kilogram	+01 5.080 234
calorie (kilogram, thermochemical)	joule	+03 4.184	hundredweight (short)	kilogram	+01 4.535 923
carat (metric)	kilogram	-04 2.00	inch	meter	-02 2.54
Celsius (temperature)	kelvin	$t_K = t_c + 273.15$	inch of mercury (32°F)	newton/meter ²	+03 3.386 389
centimeter of mercury (0°C)	newton/meter ²	+03 1.333 22	inch of mercury (60°F)	newton/meter ²	+03 3.376 85
centimeter of water (4°C)	newton/meter ²	+01 9.806 38	inch of water (39.2°F)	newton/meter ²	+02 2.490 82
chain (engineer's)	meter	+01 3.048	inch of water (60°F)	newton/meter ²	+02 2.4884
chain (surveyor's or Gunter's)	meter	+01 2.011 68	joule (international of 1948)	joule	+00 1.000 165
circular mil	meter ²	-10 5.067 074	kaysar	l/meter	+02 1.00
cord	meter ³	+00 3.624 556	kilocalorie (International Steam Table)	joule	+03 4.186 74
coulomb (international of 1948)	coulomb	-01 9.998 35	kilocalorie (mean)	joule	+03 4.190 02
cubit	meter	-01 4.572	kilocalorie (thermochemical)	joule	+03 4.184
cup	meter ³	-04 2.365 882	kilogram mass	kilogram	+00 1.00
curie	disintegration/second	+10 3.70	kilogram-force (kgf)	newton	+00 9.806 65
day (mean solar)	second (mean solar)	+04 8.64	kilopond-force	newton	+00 9.806 65
day (sidereal)	second (mean solar)	+04 8.616 409	kip	newton	+03 4.448 221
degree (angle)	radian	-02 1.745 329	knot (international)	meter/second	-01 5.144 444
denier (international)	kilogram/meter	-07 1.111 111	lambert	candela/meter ²	+04 1/π
dram (avoirdupois)	kilogram	-03 1.771 845	langley	candela/meter ²	+03 3.183 098
dram (troy or apothecary)	kilogram	-03 3.887 934	lbf (pound-force, avoirdupois)	joule/meter ²	+04 4.184
dram (U.S. fluid)	meter ³	-06 3.696 691	lbf (pound-force, avoirdupois)	newton	+00 4.448 221
dyne	newton	-05 1.00	league (British nautical)	meter	+03 5.559 552
electron volt	joule	-19 1.602 10	league (international nautical)	meter	+03 5.556
erg	joule	-07 1.00	league (statute)	meter	+03 4.828 032
Fahrenheit (temperature)	kelvin	$t_K = (5/9)(t_F + 459.67)$	light-year	meter	+15 9.460 55
Fahrenheit (temperature)	Celsius	$t_c = (5/9)(t_F - 32)$	link (engineer's)	meter	-01 3.048
farad (international of 1948)	farad	-01 9.995 05	link (surveyor's or Gunter's)	meter	-01 2.011 68
faraday (based on carbon 12)	coulomb	+04 9.648 70	liter	meter ³	-03 1.00
faraday (chemical)	coulomb	+04 9.649 57	lux	lumen/meter ²	+00 1.00
faraday (physical)	coulomb	+04 9.652 19	maxwell	weber	-08 1.00
fathom	meter	+00 1.828 8	meter	wavelengths Kr 86	+06 1.650 763
fermi (femtometer)	meter	-15 1.00	micrometer	meter	-06 1.00
			mil	meter	-05 2.54
			mile (U.S. statute)	meter	+03 1.609 344
			mile (U.K. nautical)	meter	+03 1.853 184
			mile (international nautical)	meter	+03 1.852
			mile (U.S. nautical)	meter	+03 1.852
			millibar	newton/meter ²	+02 1.00
			millimeter of mercury (0°C)	newton/meter ²	+02 1.333 224

TABLE 1-5 Metric Conversion Factors as Exact Numerical Multiples of SI Units (Concluded)

The first two digits of each numerical entry represent a power of 10. For example, the entry “-02 2.54” expresses the fact that 1 in = 2.54 × 10⁻²

To convert from	To	Multiply by	To convert from	To	Multiply by
minute (angle)	radian	-04 2.908 882	second (ephemeris)	second	+00 1.000 000
minute (mean solar)	second (mean solar)	+01 6.00	second (mean solar)	second (ephemeris)	Consult
minute (sidereal)	second (mean solar)	+01 5.983 617		American	
month (mean calendar)	second (mean solar)	+06 2.628		Ephemeris	
nautical mile (international)	meter	+03 1.852		and Nautical	
nautical mile (U.S.)	meter	+03 1.852		Almanac	
nautical mile (U.K.)	meter	+03 1.853 184	second (sidereal)	second (mean solar)	-01 9.972 695
oersted	ampere/meter	+01 7.957 747	section	meter ²	+06 2.589 988
ohm (international of 1948)	ohm	+00 1.000 495	scruple (apothecary)	kilogram	-03 1.295 978
ounce-force (avoirdupois)	newton	-01 2.780 138	shake	second	-08 1.00
ounce-mass (avoirdupois)	kilogram	-02 2.834 952	skein	meter	+02 1.097 28
ounce-mass (troy or apothecary)	kilogram	-02 3.110 347	slug	kilogram	+01 1.459 390
ounce (U.S. fluid)	meter ³	-05 2.957 352	span	meter	-01 2.286
pace	meter	-01 7.62	statampere	ampere	-10 3.335 640
parsec	meter	+16 3.083 74	statcoulomb	coulomb	-10 3.335 640
pascal	newton/meter ²	+00 1.00	statfarad	farad	-12 1.112 650
peck (U.S.)	meter ³	-03 8.809 767	stathenry	henry	+11 8.987 554
pennyweight	kilogram	-03 1.555 173	statmho	mho	-12 1.112 650
perch	meter	+00 5.0292	statohm	ohm	+11 8.987 554
phot	lumen/meter ²	+04 1.00	statute mile (U.S.)	meter	+03 1.609 344
pica (printer's)	meter	-03 4.217 517	statvolt	volt	+02 2.997 925
pint (U.S. dry)	meter ³	-04 5.506 104	stere	meter ³	+00 1.00
pint (U.S. liquid)	meter ³	-04 4.731 764	stillb	candela/meter ²	+04 1.00
point (printer's)	meter	-04 3.514 598	stoke	meter ² /second	-04 1.00
poise	(newton-second)/meter ²	-01 1.00	tablespoon	meter ³	-05 1.478 676
pole	meter	+00 5.0292	teaspoon	meter ³	-06 4.928 921
pound-force (lbf avoirdupois)	newton	+00 4.448 221	ton (assay)	kilogram	-02 2.916 666
pound-mass (lbm avoirdupois)	kilogram	-01 4.535 923	ton (long)	kilogram	+03 1.016 046
pound-mass (troy or apothecary)	kilogram	-01 3.732 417	ton (metric)	kilogram	+03 1.00
poundal	newton	-01 1.382 549	ton (nuclear equivalent of TNT)	joule	+09 4.20
quart (U.S. dry)	meter ³	-03 1.101 220	ton (register)	meter ³	+00 2.831 684
quart (U.S. liquid)	meter ³	-04 9.463 529	ton (short, 2000 lb)	kilogram	+02 9.071 847
rad (radiation dose absorbed)	joule/kilogram	-02 1.00	tonne	kilogram	+03 1.00
Rankine (temperature)	kelvin	$t_K = (5/9)t_R$	torr (0°C)	newton/meter ²	+02 1.333 22
rayleigh (rate of photon emission)	1/second-meter ²	+10 1.00	township	meter ²	+07 9.323 957
rhe	meter ² /(newton-second)	+01 1.00	unit pole	weber	-07 1.256 637
rod	meter	+00 5.0292	volt (international of 1948)	volt	+00 1.000 330
roentgen	coulomb/kilogram	-04 2.579 76	watt (international of 1948)	watt	+00 1.000 165
rutherford	disintegration/second	+06 1.00	yard	meter	-01 9.144
second (angle)	radian	-06 4.848 136	year (calendar)	second (mean solar)	+07 3.1536
			year (sidereal)	second (mean solar)	+07 3.155 815
			year (tropical)	second (mean solar)	+07 3.155 692
			year 1900, tropical, Jan., day 0, hour 12	second (ephemeris)	+07 3.155 692
			year 1900, tropical, Jan., day 0, hour 12	second	+07 3.155 692

TABLE 1-6 Alphabetical Listing of Common Conversions

To convert from	To	Multiply by	To convert from	To	Multiply by
Acres	Square feet	43,560	B.t.u. (60°F.) per degree Fahrenheit	Calories per degree centigrade	453.6
Acres	Square meters	4074	Bushels (U.S. dry)	Cubic feet	1,2444
Acres	Square miles	0.001563	Bushels (U.S. dry)	Cubic meters	0.03524
Acres-feet	Cubic meters	1233	Calories, gram	B.t.u.	3,968 × 10 ⁻³
Amperes-hours (absolute)	Coulombs (absolute)	3600	Calories, gram	Foot-pounds	3.087
Angstrom units	Inches	3.937 × 10 ⁻⁹	Calories, gram	Joules	4.1868
Angstrom units	Meters	1 × 10 ⁻¹⁰	Calories, gram	Liter-atmospheres	4.130 × 10 ⁻²
Angstrom units	Microns	1 × 10 ⁻⁴	Calories, gram	Horsepower-hours	1,5591 × 10 ⁻⁶
Atmospheres	Millimeters of mercury at 32°F	760	Calories, gram, per gram, per degree C.	Joules per kilogram per degree Kelvin	4186.8
Atmospheres	Dynes per square centimeter	101,325	Calories, kilogram	Kilowatt-hours	0.0011626
Atmospheres	Newtons per square meter	33.90	Calories, kilogram per second	Kilowatts	4.185
Atmospheres	Feet of water at 39.1°F	1033.3	Candle power (spherical)	Lumens	12,556
Atmospheres	Grams per square centimeter	29,921	Carats (metric)	Grams	0.2
Atmospheres	Inches of mercury at 32°F	2116.3	Centigrade heat units	B.t.u.	1.8
Atmospheres	Pounds per square foot	14.696	Centimeters	Angstrom units	1 × 10 ⁸
Atmospheres	Pounds per square inch	94	Centimeters	Feet	0.03281
Bags (cement)	Pounds (cement)	376	Centimeters	Inches	0.3937
Barrels (cement)	Cubic meters	0.15899	Centimeters	Meters	0.01
Barrels (oil)	Gallons	42	Centimeters	Microns	10,000
Barrels (oil)	Cubic meters	0.11924	Centimeters of mercury at 0°C.	Atmospheres	0.013158
Barrels (U.S. liquid)	Gallons	31.5	Centimeters of mercury at 0°C.	Feet of water at 39.1°F	0.4460
Barrels (U.S. liquid)	Gallons per minute	0.02917	Centimeters of mercury at 0°C.	Newtons per square meter	1333.2
Bars	Atmospheres	0.9869	Centimeters of mercury at 0°C.	Pounds per square foot	27.845
Bars	Newtons per square meter	1 × 10 ⁵	Centimeters per second	Pounds per square inch	0.19337
Bars	Pounds per square inch	14.504	Centimeters of water at 4°C.	Newtons per square meter	98.064
Board feet	Cubic feet	1/2	Centistokes	Square meters per second	1 × 10 ⁻⁶
Boiler horsepower	B.t.u. per hour	33,480	Circular mils	Square centimeters	5,067 × 10 ⁻⁶
Boiler horsepower	Kilowatts	9,803	Circular mils	Square inches	7.854 × 10 ⁻⁷
B.t.u.	Calories (gram)	0.55556	Cords	Cubic feet	128
B.t.u.	Centigrade heat units (c.h.u. or p.c.u.)	777.9	Cubic centimeters	Cubic foot	3,532 × 10 ⁻⁵
B.t.u.	Horsepower-hours	3,929 × 10 ⁻⁴	Cubic centimeters	Gallons	2,6417 × 10 ⁻⁴
B.t.u.	Joules	1055.1	Cubic centimeters	Ounces (U.S. fluid)	0.03381
B.t.u.	Liter-atmospheres	10.41	Cubic centimeters	Quarts (U.S. fluid)	0.0010567
B.t.u.	Pounds carbon to CO ₂	6.88 × 10 ⁻⁵	Cubic feet	Bushels (U.S.)	0.8036
B.t.u.	Pounds water evaporated from and at 212°F	0.001036	Cubic feet	Cubic centimeters	28,317
B.t.u.	Cubic foot-atmospheres	0.3676	Cubic feet	Cubic meters	0.028317
B.t.u.	Kilowatt-hours	2,930 × 10 ⁻⁴	Cubic feet	Cubic yards	0.03704
B.t.u. per cubic foot	Joules per cubic meter	37,260	Cubic feet	Gallons	7.481
B.t.u. per hour	Watts	0.29307	Cubic foot-atmospheres	Liters	28.316
B.t.u. per minute	Horsepower	0.02357	Cubic foot-atmospheres	Foot-pounds	2116.3
B.t.u. per pound	Joules per kilogram	2326	Cubic foot of water (60°F.)	Liter-atmospheres	28.316
B.t.u. per pound per degree Fahrenheit	Calories per gram, per degree centigrade	1	Cubic foot per minute	Pounds	62.37
B.t.u. per pound per degree Fahrenheit	Joules per kilogram per degree Kelvin	4186.8	Cubic feet per second	Cubic centimeters per second	472.0
B.t.u. per second	Watts	1054.4	Cubic inches	Gallons per second	0.1247
B.t.u. per square foot per hour	Joules per square meter per second	3,1546	Curies	Gallons per minute	448.8
B.t.u. per square foot per minute	Kilowatts per square foot	0.1758	Curies	Million gallons per day	0.64632
B.t.u. per square foot per second	Calories, gram (15°C.), per square centimeter per second for a temperature gradient of 1°F. per inch	1.2405	Degrees	Cubic meters	1.6887 × 10 ⁻⁵
			Drams (apothecaries' or Troy)	Cubic meters	0.76456
				Disintegrations per minute	2.2 × 10 ¹²
				Coulombs per minute	1.1 × 10 ¹²
				Radians	0.017453
				Grams	3.888

TABLE 1-6 Alphabetical Listing of Common Conversions (Concluded)

To convert from	To	Multiply by	To convert from	To	Multiply by
Drams (avoirdupois)	Grams	1.7719	Horsepower (British)	Pounds water evaporated per hour at 212°F	2.64
Dynes	Newtons	1×10^{-5}	Horsepower (metric)	Foot-pounds per second	542.47
Ergs	Joules	1×10^{-7}	Horsepower (metric)	Kilogram-meters per second	75.0
Faradays	Coulombs (abs.)	96,500	Hours (mean solar)	Seconds	3600
Fathoms	Feet	6	Inches	Meters	0.0254
Feet per minute	Meters per second	0.3048	Inches of mercury at 60°F	Newtons per square meter	3376.9
Feet per minute	Miles per hour	0.5080	Inches of water at 60°F	Newtons per square meter	248.84
Feet per (second) ²	Meters per (second) ²	0.011364	Joules (absolute)	B.t.u. (mean)	9.480×10^{-4}
Feet of water at 39.2°F	Meters per square meter	0.3048	Joules (absolute)	Calories, gram (mean)	0.2389
Foot-pounds	Newtons per square meter	2989	Joules (absolute)	Cubic foot-atmospheres	0.3485
Foot-pounds	B.t.u.	3.995×10^{-5}	Joules (absolute)	Foot-pounds	0.7376
Foot-pounds	Joules	0.04214	Joules (absolute)	Kilowatt-hours	2.7778×10^{-7}
Foot-pounds	Liter-atmospheres	4.159×10^{-4}	Joules (absolute)	Liter-atmospheres	0.009869
Foot-pounds	B.t.u.	0.0012856	Kilocalories	Joules	4186.8
Foot-pounds	Calories, gram	0.3239	Kilograms	Pounds (avoirdupois)	2.2046
Foot-pounds	Foot-pounds	32.174	Kilograms force	Newtons	9.807
Foot-pounds	Horsepower-hours	5.051×10^{-7}	Kilograms per square centimeter	Pounds per square inch	14.223
Foot-pounds	Kilowatt-hours	3.766×10^{-7}	Kilometers	Miles	0.6214
Foot-pounds	Liter-atmospheres	0.013381	Kilowatt-hours	B.t.u.	341.4
Foot-pounds force	Joules	1.3558	Kilowatt-hours	Foot-pounds	2.6552×10^6
Foot-pounds per second	Horsepower	0.0018182	Kilowatts	Horsepower	1.3410
Foot-pounds per second	Kilowatts	0.0013558	Knots (international)	Meters per second	0.5144
Furlongs	Miles	0.125	Knots (nautical miles per hour)	Miles per hour	1.1516
Gallons (U.S. liquid)	Barrels (U.S. liquid)	0.03175	Lamberts	Candles per square inch	2.054
Gallons	Cubic meters	0.003785	Liter-atmospheres	Cubic foot-atmospheres	0.03532
Gallons	Cubic feet	0.13368	Liter-atmospheres	Foot-pounds	74.74
Gallons	Gallons (Imperial)	0.8327	Liters	Cubic feet	0.03532
Gallons	Liters	3.785	Liters	Cubic meters	0.001
Gallons	Ounces (U.S. fluid)	128	Liters	Gallons	0.26418
Gallons per minute	Cubic feet per hour	8.021	Lumens	Watts	0.001496
Gallons per minute	Cubic feet per second	0.002228	Micrometers	Meters	1×10^{-6}
Grains	Grams	0.06480	Microns	Angstrom units	1×10^{-4}
Grains	Pounds	$1/7000$	Microns	Meters	1×10^{-6}
Grains per cubic foot	Grams per cubic meter	2.2884	Miles (nautical)	Feet	6080
Grains per gallon	Parts per million	17.118	Miles (nautical)	Miles (U.S. statute)	1.1516
Grams	Drams (avoirdupois)	0.5644	Miles	Feet	5280
Grams	Drams (troy)	0.2572	Miles	Meters	1609.3
Grams	Grains	15.432	Miles per hour	Feet per second	1.4667
Grams	Kilograms	0.001	Miles per hour	Meters per second	0.4470
Grams	Pounds (avoirdupois)	0.0022046	Millifiters	Cubic centimeters	1
Grams	Pounds (troy)	0.002679	Millimeters	Meters	0.001
Grams per cubic centimeter	Pounds per cubic foot	62.43			

TABLE 1-7 Common Units and Conversion Factors*

Mass (M)	1 pound mass = 453.5924 grams = 0.45359 kilograms = 7000 grains 1 slug = 32.174 pounds mass 1 ton (short) = 2000 pounds mass 1 ton (long) = 2240 pounds mass 1 ton (metric) = 1000 kilograms = 2204.62 pounds mass 1 pound mole = 453.59 gram moles	1 atm = 760 millimeters of mercury at 0°C (density 13.5951 g/cm ³) = 29.921 inches of mercury at 32°F = 14.696 pounds force/square inch = 33.899 feet of water at 39.1°F = 1.01325 × 10 ⁶ dynes/square centimeter = 1.01325 × 10 ⁵ Newtons/square meter
Length (L)	1 foot = 30.480 centimeters = 0.3048 meters 1 inch = 2.54 centimeters = 0.0254 meters 1 mile (U.S.) = 1.60935 kilometers 1 yard = 0.9144 meters	Density (M/L ³) 1 pound mass/cubic foot = 0.01601846 grams/cubic centimeter = 16.01846 kilogram/cubic meter
Area (L ²)	1 square foot = 929.0304 square centimeters = 0.09290304 square meters 1 square inch = 6.4516 square centimeters 1 square yard = 0.836127 square meters	Energy (H or FL) 1 British thermal unit = 251.98 calories = 1054.4 joules = 777.97 foot-pounds force = 10.409 liter-atmospheres = 0.2930 watt-hour
Volume (L ³)	1 cubic foot = 28,316.85 cubic centimeters = 0.02831685 cubic meters = 28.31685 liters = 7.481 gallons (U.S.) 1 gallon = 3.7853 liters = 231 cubic inches	Diffusivity (L ² /θ) 1 square foot/hour = 0.258 cm ² /s = 2.58 × 10 ⁻⁵ m ² /s
Time (θ)	1 hour = 60 minutes = 3600 seconds	Viscosity (M/Lθ) 1 pound mass/foot hour = 0.00413 g/cm s 0.000413 kg/m s 1 centipoise = 0.01 poise = 0.01 g/cm s = 0.001 kg/m s = 0.000672 lbm/ft s = 0.0000209 lbf/s/ft ²
Temperature (T)	1 centigrade or Celsius degree = 1.8 Fahrenheit degree Temperature, Kelvin = T°C + 273.15 Temperature, Rankine = T°F + 459.7 Temperature, Fahrenheit = 9/5 T°C + 32 Temperature, centigrade or Celsius = 5/9 (T°F - 32) Temperature, Rankine = 1.8 T K	Thermal conductivity [H/θL ² (T/L)] 1 Btu/hr ft ² (°F/ft) = 0.00413 cal/s cm ² (°C/cm) = 1.728 J/s m ² (°C/m)
Force (F)	1 pound force = 444,822.2 dynes = 4.448222 Newtons = 32.174 poundals	Heat transfer coefficient 1 Btu/hr ft ² °F = 5.678 J/s m ² °C
Pressure (F/L ²)	Normal atmospheric pressure	Heat capacity (H/MT) 1 Btu/lbm °F = 1 cal/g °C = 4184 J/kg °C
		Gas constant 1.987 Btu/lbm mole °R = 1.987 cal/mol K = 82.057 atm cm ³ /mol K = 0.7302 atm ft ³ /lb mole °F = 10.73 (lb _m /in. ²) (ft ³)/lb mole °R = 1545 (lb _f /ft ²) (ft ³)/lb mole °R = 8.314 (N/m ²) (m ³)/mol K
		Gravitational acceleration g = 9.8066 m/s ² = 32.174 ft/s ²

NOTE: U.S. customary units; or British units, on left and SI units on right.
*Adapted from Faust et al., *Principles of Unit Operations*, John Wiley and Sons, 1980.

TABLE 1-8 Kinematic-Viscosity Conversion Formulas

Viscosity scale	Range of t, sec	Kinematic viscosity, stokes
Saybolt Universal	32 < t < 100	0.00226t - 1.95/t
	t > 100	0.00220t - 1.35/t
Saybolt Furol	25 < t < 40	0.0224t - 1.84/t
	t > 40	0.0216t - 0.60/t
Redwood No. 1	34 < t < 100	0.00260t - 1.79/t
	t > 100	0.00247t - 0.50/t
Redwood Admiralty Engler		0.027t - 20t 0.00147t - 3.74/t

TABLE 1-9 Values of the Gas-Law Constant

Temp. scale	Press. units	Vol. units	Wt. units	Energy units	R
Kelvin			g-moles	calories	1.9872
			g-moles	joules (abs)	8.3144
			g-moles	joules (int)	8.3130
			g-moles	atm cm ³	82.057
			g-moles	atm liters	0.08205
			g-moles	mm Hg-liters	62.361
			g-moles	bar-liters	0.08314
			g-moles	kg/(cm ²)(liters)	0.08478
			lb-moles	atm-ft ³	1.314
			lb-moles	mm Hg-ft ³	998.9
			lb-moles	chu or pcu	1.9872
			lb-moles	Btu	1.9872
			lb-moles	hp-hr	0.0007805
			lb-moles	kw-hr	0.0005819
Rankine			lb-moles	atm-ft ³	0.7302
			lb-moles	in Hg-ft ³	21.85
			lb-moles	mm Hg-ft ³	555.0
			lb-moles	(lb _f)(ft ³)/in ²	10.73
			lb-moles	ft-lb	1545.0

TABLE 1-10 United States Customary System of Weights and Measures

Linear Measure	
12 inches (in) or (") = 1 foot (ft) or (')	
3 feet = 1 yard (yd)	
16.5 feet } = 1 rod (rd)	
5.5 yards } = 1 rod (rd)	
5280 feet } = 1 mile (mi)	
320 rods } = 1 mile (mi)	
1 mil = 0.001 inch	
<i>Nautical:</i>	
6080.2 feet = 1 nautical mile	
6 feet = 1 fathom	
120 fathoms = 1 cable length	
1 knot = 1 nautical mile per hour	
60 nautical miles = 1° of latitude	
Square Measure	
144 sq. inches (sq. in) or (in ²) or (□") = 1 sq. foot (ft ²) or (□')	
9 sq. feet (ft ²) (□') = 1 sq. yard (yd ²)	
30.25 sq. yards = 1 sq. rod, pole, or perch	
160 sq. rods = $\left\{ \begin{array}{l} 10 \text{ sq. chains} \\ 43,560 \text{ sq. ft} \end{array} \right\} = 1 \text{ acre}$	
640 acres = 1 sq. mile = 1 section	
1 circular inch (area of circle of 1 inch diameter) = 0.7854 sq. inch	
1 sq. inch = 1.2732 circular inch	
1 circular mil = area of circle of 0.001 inch diameter	
1,000,000 circular mils = 1 circular inch	
Circular Measure	
60 seconds (") (sec) = 1 minute (min) or (')	
60 minutes (') = 1 degree (°)	
90 degrees (°) = 1 quadrant	
360 degrees (°) = 1 circumference	
57.29578 degrees $\left\{ \begin{array}{l} = 1 \text{ radian (rad.)} \\ = 57^{\circ} 17' 44.81'' \end{array} \right.$	
Volume Measure	
<i>Solid:</i>	
1728 cubic in (cu. in) (in ³) = 1 cubic foot (cu. ft)(ft ³)	
27 cu. ft = 1 cubic yard (cu. yd)	
<i>Dry Measure:</i>	
2 pints = 1 quart	
8 quarts = 1 peck	
4 pecks = 1 bushel	
1 United States Winchester bushel = 2150.42 cubic inches	
<i>Liquid:</i>	
4 gills = 1 pint (pt)	
2 pints = 1 quart (qt)	
4 quarts = 1 gallon (gal)	
7.4805 gallons = 1 cubic foot	
<i>Apothecaries' Liquid:</i>	
60 minims (min. or \mathfrak{m}) = 1 fluid dram or drachm	
8 drams (\mathfrak{d}) = 1 fluid ounce	
16 ounces (oz. \mathfrak{z}) = 1 pint	
Avoirdupois Weight	
16 drams = 437.5 grains = 1 ounce (oz)	
16 ounces = 7000 grains = 1 pound (lb)	
100 pounds = 1 hundredweight (cwt)	
2000 pounds = 1 short ton; 2240 pounds = 1 long ton	
Troy Weight	
24 grains = 1 pennyweight (dwt)	
20 pennyweights = 1 ounce (oz)	
12 ounces = 1 pound (lb)	
Apothecaries' Weight	
20 grains (gr) = 1 scruple (\mathfrak{s})	
3 scruples = 1 dram (\mathfrak{d})	
8 drams = 1 ounce (\mathfrak{z})	
12 ounces = 1 pound (lb)	

TABLE 1-11 Temperature Conversion Formulas

$$\begin{aligned} ^{\circ}\text{F} &= (^{\circ}\text{C} \times 5/9) + 32 \\ ^{\circ}\text{C} &= (^{\circ}\text{F} - 32) \times 5/9 \\ ^{\circ}\text{R} &= ^{\circ}\text{F} + 459.69 \\ ^{\circ}\text{K} &= ^{\circ}\text{C} + 273.15 \\ ^{\circ}\text{K} &= ^{\circ}\text{R} \times 5/9 \end{aligned}$$

Temperature difference, ΔT
 $^{\circ}\text{F} = ^{\circ}\text{C} \times 9/5$

NOTE: An extensive table of temperature conversions may be found in the sixth edition of the *Handbook* (Table 1-12).

TABLE 1-13 Wire and Sheet-Metal Gauges*

As a number of gauges are in use for various shapes and metals, it is advisable to state the thickness in thousandths when specifying gauge number. Values in approximate decimals of an inch

Gauge number	American (AWG) or Brown & Sharpe (B & S) (for nonferrous wire and sheet)†	U.S. Steel Wire (Stl) Washburn & Moen or Roebbing or Am. Steel & Wire Co. [A. (steel) WG] (for steel wire)	Birming-ham (BWG) (for steel or wire)	U.S. Standard (for sheet and plate metal, wrought iron)	Standard Birmingham (BC) (for sheet and hoop metal)	Imperial Standard and Wire Gauge (SWG) (British legal standard)	Gauge number	American (AWG) or Brown & Sharpe (B & S) (for nonferrous wire and sheet)†	U.S. Steel Wire (Stl) Washburn & Moen or Roebbing or Am. Steel & Wire Co. [A. (steel) WG] (for steel wire)	Birming-ham (BWG) (for steel or wire)	U.S. Standard (for sheet and plate metal, wrought iron)	Standard Birmingham (BC) (for sheet and hoop metal)	Imperial Standard and Wire Gauge (SWG) (British legal standard)	Gauge number	American (AWG) or Brown & Sharpe (B & S) (for nonferrous wire and sheet)†	U.S. Steel Wire (Stl) Washburn & Moen or Roebbing or Am. Steel & Wire Co. [A. (steel) WG] (for steel wire)	Birming-ham (BWG) (for steel or wire)	U.S. Standard (for sheet and plate metal, wrought iron)	Standard Birmingham (BC) (for sheet and hoop metal)	Imperial Standard and Wire Gauge (SWG) (British legal standard)	Gauge number		
0000000	—	0.4900	—	—	0.6666	0.500	0000000	0.0159	0.0181	0.018	0.0188	0.0196	0.018	0.018	0.0159	0.0181	0.018	0.0188	0.0196	0.018	0.018	0.018	0.018
000000	—	.4615	—	—	.6250	.464	0000000	.0142	.0173	.016	.0172	.0175	.0164	.0175	.0142	.0173	.016	.0172	.0175	.0164	.0175	.0175	.0175
00000	—	.4305	—	—	.5883	.432	000000	.0136	.0162	.014	.0156	.0156	.0148	.0156	.0136	.0162	.014	.0156	.0156	.0148	.0156	.0156	.0156
0000	0.460	.3938	0.454	—	.5416	.400	0000	.0113	.0150	.013	.0141	.0139	.0136	.0141	.0113	.0150	.013	.0141	.0139	.0136	.0141	.0141	.0141
000	.410	.3625	.425	—	.5000	.372	000	.0100	.0140	.012	.0125	.0123	.0124	.0125	.0100	.0140	.012	.0125	.0123	.0124	.0125	.0125	.0125
00	.365	.3310	.380	—	.4452	.348	00	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
0	.325	.3065	.340	—	.3964	.324	0	.0089	.0132	.010	.0109	.0110	.0116	.0109	.0089	.0132	.010	.0109	.0110	.0116	.0109	.0109	.0109
1	.289	.2830	.300	—	.3532	.300	1	.0080	.0128	.009	.0102	.0098	.0108	.0098	.0080	.0128	.009	.0102	.0098	.0108	.0098	.0098	.0098
2	.258	.2625	.284	—	.3147	.276	2	.0071	.0118	.008	.0084	.0087	.0100	.0084	.0071	.0118	.008	.0084	.0087	.0100	.0087	.0087	.0087
3	.229	.2437	.259	0.239	.2804	.252	3	.0063	.0104	.007	.0078	.0077	.0092	.0078	.0063	.0104	.007	.0078	.0077	.0092	.0077	.0077	.0077
4	.204	.2253	.238	.224	.2500	.232	4	.0056	.0095	.005	.0078	.0075	.0084	.0078	.0056	.0095	.005	.0078	.0075	.0084	.0075	.0075	.0075
5	.182	.2070	.220	.209	.2225	.212	5	.0050	.0090	.004	.0070	.0068	.0076	.0070	.0050	.0090	.004	.0070	.0068	.0076	.0068	.0068	.0068
6	.162	.1920	.203	.194	.1981	.192	6	.0045	.0085	—	.0066	.0062	.0068	.0066	.0045	.0085	—	.0066	.0062	.0068	.0062	.0062	.0062
7	.144	.1770	.180	.179	.1764	.176	7	.0040	.0080	—	.0062	.0058	.0062	.0062	.0040	.0080	—	.0062	.0058	.0062	.0058	.0058	.0058
8	.128	.1620	.165	.164	.1570	.160	8	.0035	.0075	—	.0055	.0052	.0058	.0055	.0035	.0075	—	.0055	.0052	.0058	.0052	.0052	.0052
9	.114	.1483	.148	.150	.1398	.144	9	.0031	.0070	—	.0050	.0048	.0052	.0050	.0031	.0070	—	.0050	.0048	.0052	.0048	.0048	.0048
10	.102	.1350	.134	.135	.1250	.128	10	—	.0066	—	.0044	.0042	.0048	.0044	—	.0066	—	.0044	.0042	.0048	.0042	.0042	.0042
11	.091	.1205	.120	.120	.1113	.116	11	—	.0062	—	.0040	.0038	.0042	.0040	—	.0062	—	.0040	.0038	.0042	.0038	.0038	.0038
12	.081	.1055	.109	.105	.0991	.104	12	—	.0058	—	.0038	.0036	.0040	.0038	—	.0058	—	.0038	.0036	.0040	.0036	.0036	.0036
13	.072	.0915	.095	.090	.0882	.092	13	—	.0055	—	.0035	.0032	.0038	.0035	—	.0055	—	.0035	.0032	.0038	.0032	.0032	.0032
14	.064	.0800	.083	.075	.0785	.080	14	—	.0052	—	.0032	.0030	.0034	.0032	—	.0052	—	.0032	.0030	.0034	.0030	.0030	.0030
15	.057	.0720	.072	.067	.0699	.072	15	—	.0050	—	.0030	.0028	.0032	.0030	—	.0050	—	.0030	.0028	.0032	.0028	.0028	.0028
16	.051	.0625	.065	.060	.0625	.064	16	—	.0048	—	.0028	.0026	.0030	.0028	—	.0048	—	.0028	.0026	.0030	.0026	.0026	.0026
17	.045	.0540	.058	.054	.0556	.056	17	—	.0046	—	.0026	.0024	.0028	.0026	—	.0046	—	.0026	.0024	.0028	.0024	.0024	.0024
18	.040	.0475	.049	.0478	.0495	.048	18	—	.0044	—	.0024	.0022	.0026	.0024	—	.0044	—	.0024	.0022	.0026	.0022	.0022	.0022
19	.036	.0410	.042	.0418	.0440	.040	19	—	.0042	—	.0022	.0020	.0024	.0022	—	.0042	—	.0022	.0020	.0024	.0020	.0020	.0020
20	.032	.0348	.035	.0359	.0392	.036	20	—	.0040	—	.0020	.0018	.0022	.0020	—	.0040	—	.0020	.0018	.0024	.0018	.0018	.0018
21	.0285	.0317	.032	.0329	.0349	.032	21	—	.0038	—	.0018	.0016	.0020	.0018	—	.0038	—	.0018	.0016	.0020	.0016	.0016	.0016
22	.0253	.0286	.028	.0299	.0313	.028	22	—	.0036	—	.0016	.0014	.0018	.0016	—	.0036	—	.0016	.0014	.0018	.0014	.0014	.0014
23	.0226	.0258	.025	.0269	.0278	.024	23	—	.0034	—	.0014	.0012	.0016	.0014	—	.0034	—	.0014	.0012	.0018	.0012	.0012	.0012
24	.0201	.0230	.022	.0239	.0248	.022	24	—	.0032	—	.0012	.0010	.0014	.0012	—	.0032	—	.0012	.0010	.0018	.0010	.0010	.0010
25	.0179	.0204	.020	.0209	.0220	.020	25	—	.0030	—	.0010	.0008	.0012	.0010	—	.0030	—	.0010	.0008	.0018	.0008	.0008	.0008

Metric wire gauge is 10 times the diameter in millimeters.

* Courtesy of Dr. Lewis V. Judson with I. H. Fullmer, National Bureau of Standards.

† Sometimes used for iron wire.

‡ Sometimes used for copper plate and for steel plate 12 gauge and heavier and for steel tubes.

TABLE 1-14 Fundamental Physical Constants

1 sec = 1.00273791 sidereal seconds	sec = mean solar second
$g_0 = 9.80665 \text{ m/sec}^2$	Definition: g_0 = standard gravity
1 liter = 0.001 cu. m	
1 atm = 101,325 newtons/sq m	Definition: atm = standard atmosphere
1 mm Hg (pressure) = $(1/760)$ atm	mm Hg (pressure) = standard millimeter mercury
$= 133.3224 \text{ newtons/sq m}$	
1 int ohm = 1.000495 ± 0.000015 abs ohm	int = international; abs = absolute
1 int amp = 0.999835 ± 0.000025 abs amp	amp = ampere
1 int coul = 0.999835 ± 0.000025 abs coul	coul = coulomb
1 int volt = 1.000330 ± 0.000029 abs volt	
1 int watt = 1.000165 ± 0.000052 abs watt	
1 int joule = 1.000165 ± 0.000052 abs joule	
$T_{WC} = 273.150 \pm 0.010^\circ\text{K}$	Absolute temperature of the ice point, 0°C
$(PV)_{WC}^{30} = (RT)_{WC} = 2271.16 \pm 0.04 \text{ abs joule/mole}$	PV product for ideal gas at 0°C
$= 22,414.6 \pm 0.4 \text{ cu. cm atm/mole}$	
$= 22,4146 \pm 0.0004 \text{ liter atm/mole}$	R = gas constant per mole
$R = 8.31439 \pm 0.00034 \text{ abs joule/deg mole}$	
$= 1.98719 \pm 0.00013 \text{ cal/deg mole}$	
$= 82.0567 \pm 0.0034 \text{ cu. cm atm/deg mole}$	
$= 0.0820567 \pm 0.0000034 \text{ liter atm/deg mole}$	
$\ln 10 = 2.302585$	\ln = natural logarithm (base e)
$R \ln 10 = 19.14460 \pm 0.00078 \text{ abs joule/deg mole}$	
$= 4.57567 \pm 0.00030 \text{ cal/deg mole}$	
$N = (6.02283 \pm 0.0022) \times 10^{23}/\text{mole}$	N = Avogadro number
$h = (6.6242 \pm 0.0044) \times 10^{-34} \text{ joule sec}$	h = Planck constant
$c = (2.99776 \pm 0.00008) \times 10^8 \text{ m/sec}$	c = velocity of light
$(h^2/8\pi^2k) = (4.0258 \pm 0.0037) \times 10^{-39} \text{ g sq cm deg}$	Constant in rotational partition function of gases
$(h/8\pi^2c) = (2.7986 \pm 0.0018) \times 10^{-39} \text{ g cm}$	Constant relating wave number and moment of inertia
$Z = Nhc = 11.9600 \pm 0.0036 \text{ abs joule cm/mole}$	Z = constant relating wave number and energy per mole
$= 2.85551 \pm 0.0009 \text{ cal cm/mole}$	
$(Z/R) = (hc/k) = c_2 = 1.43847 \pm 0.00045 \text{ cm deg}$	c_2 = second radiation constant
$\mathcal{F} = 96,501.2 \pm 10.0 \text{ int coul/g-equiv or int joule/int volt g-equiv}$	\mathcal{F} = Faraday constant
$= 96,485.3 \pm 10.0 \text{ abs coul/g-equiv or abs joule/abs volt g-equiv}$	
$= 23,068.1 \pm 2.4 \text{ cal/int volt g-equiv}$	
$= 23,060.5 \pm 2.4 \text{ cal/abs volt g-equiv}$	
$e = (1.60199 \pm 0.00060) \times 10^{-19} \text{ abs coul}$	e = electronic charge
$= (1.60199 \pm 0.00060) \times 10^{-20} \text{ abs emu}$	
$= (4.80239 \pm 0.00180) \times 10^{-10} \text{ abs esu}$	
1 int electron-volt/molecule = 96,501.2 ± 10 int joule/mole	
$= 23,068.1 \pm 2.4 \text{ cal/mole}$	
1 abs electron-volt/molecule = 96,485.3 ± 10. abs joule/mole	
$= 23,060.5 \pm 2.4 \text{ cal/mole}$	
1 int electron-volt = $(1.60252 \pm 0.00060) \times 10^{-12} \text{ erg}$	
1 abs electron-volt = $(1.60199 \pm 0.00060) \times 10^{-12} \text{ erg}$	
$hc = (1,23916 \pm 0.00032) \times 10^{-4} \text{ int electron-volt cm}$	Constant relating wave number and energy per molecule
$= (1,23957 \pm 0.00032) \times 10^{-4} \text{ abs electron-volt cm}$	
$k = (8.61442 \pm 0.00100) \times 10^{-5} \text{ int electron-volt/deg}$	k = Boltzmann constant
$= (8.61727 \pm 0.00100) \times 10^{-5} \text{ abs electron-volt/deg}$	
$= (R/N) = (1.38048 \pm 0.00050) \times 10^{-23} \text{ joule/deg}$	
1 IT cal = $(1/860) = 0.00116279 \text{ int watt-hr}$	Definition of IT cal: IT = International steam tables
$= 4.18605 \text{ int joule}$	
$= 4.18674 \text{ abs joule}$	
$= 1.000654 \text{ cal}$	cal = thermochemical calorie
1 cal = 4.1840 abs joule	Definition: cal = thermochemical calorie
$= 4.1833 \text{ int joule}$	
$= 41.2929 \pm 0.0020 \text{ cu. cm atm}$	
$= 0.0412929 \pm 0.0000020 \text{ liter atm}$	
1 IT cal/g = 1.8 Btu/lb	Definition of Btu: Btu = IT British Thermal Unit
1 Btu = 251.996 IT cal	
$= 0.293018 \text{ int watt-hr}$	
$= 1054.866 \text{ int joule}$	
$= 1055.040 \text{ abs joule}$	
$= 252.161 \text{ cal}$	cal = thermochemical calorie
1 horsepower = 550 ft-lb (wt)/sec	Definition of horsepower (mechanical): lb (wt) = weight of 1 lb at standard gravity
$= 745.578 \text{ int watt}$	Definition of in: in = U.S. inch
$= 745.70 \text{ abs watt}$	ft = U.S. foot (1 ft = 12 in)
1 in = $(1/0.3937) = 2.54 \text{ cm}$	
1 ft = 0.304800610 m	
1 lb = 453.5924277 g	Definition; lb = avoirdupois pound
1 gal = 231 cu. in	Definition; gal = U.S. gallon
$= 0.133680555 \text{ cu. ft}$	
$= 3.785412 \times 10^{-3} \text{ cu. m}$	
$= 3.785412 \text{ liter}$	

CONVERSION OF VALUES FROM U.S. CUSTOMARY UNITS TO SI UNITS

American engineers are probably more familiar with the magnitude of physical entities in U.S. customary units than in SI units. Consequently, errors made in the conversion from one set of units to the other may go undetected. The following six examples will show how to convert the elements in six dimensionless groups. Proper conversions will result in the same numerical value for the dimensionless number. The dimensionless numbers used as examples are the Reynolds, Prandtl, Nusselt, Grashof, Schmidt, and Archimedes numbers.

Table 1-7 provides a number of useful conversion factors. To make a conversion of an element in U.S. customary units to SI units, one multiplies the value of the U.S. customary unit, found on the left side in the table, by the equivalent value on the right side. For example, to convert 10 British thermal units to joules, one multiplies 10 by 1054.4 to obtain 10544 joules.

In each example, the initial values of the factors are expressed in U.S. customary units, and the dimensionless value is calculated. Then the factors are converted to SI units, and the dimensionless value is recalculated. The two dimensionless values will be approximately the same. (Small variations occur due to the number of significant figures carried in the solution.)

Example 1. Calculation of a Reynolds Number

$$N_{Re} = \frac{DV\rho}{\mu}$$

U.S. customary units

$$\begin{aligned} D &= 3 \text{ in.} = \frac{3}{12} \text{ ft} \\ V &= 6 \text{ ft/s} \\ \rho &= 0.08 \text{ lbm/ft}^3 \\ \mu &= 0.015 \text{ cp} = (0.015)(0.000672) \text{ lbm/ft-s} \end{aligned}$$

$$N_{Re} = \frac{(3/12)(6)(0.08)}{(0.015)(0.000672)} = 11,904$$

SI units

$$\begin{aligned} D &= (3)(0.0254) \text{ m} \\ V &= (6)(0.3048) \text{ m/s} \\ \rho &= (0.08)(16.018) \text{ kg/m}^3 \\ \mu &= (0.015)(0.001) \text{ kg/m-s} \end{aligned}$$

$$N_{Re} = \frac{(3 \times 0.0254)(6 \times 0.3048)(0.08 \times 16.018)}{(0.015)(0.001)} = 11,904$$

Example 2. Calculation of a Prandtl Number

$$N_{Pr} = \frac{C_p\mu}{k}$$

U.S. customary units

$$\begin{aligned} \gamma_p &= 0.47 \text{ Btu/lbm } ^\circ\text{F} \\ \mu &= 15 \text{ centipoise} = (15)(0.000672)(3600) \text{ lbm/ft-hr} \\ k &= 0.065 \text{ Btu/hr-ft}^2 \text{ (} ^\circ\text{F/ft)} \end{aligned}$$

$$N_{Pr} = \frac{(0.47)(15 \times 0.000672 \times 3600)}{0.065} = 262.4$$

SI units

$$\begin{aligned} \gamma &= (0.47)(4184) \text{ J/kg } ^\circ\text{C} \\ \mu &= (15)(0.001) \text{ kg/m-s} \\ k &= (0.065)(1.728) \text{ J/s-m}^2 \text{ (} ^\circ\text{C/m)} \end{aligned}$$

$$N_{Pr} = \frac{(0.47)(4184)(15)(0.001)}{(0.065)(1.728)} = 262.6$$

(Difference due to rounding)

Example 3. Calculation of a Nusselt Number

$$N_{Nu} = \frac{hD}{k}$$

U.S. customary units

$$\begin{aligned} h &= 200 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F} \\ D &= 1.5 \text{ in.} = 1.5/12 \text{ ft} \\ k &= 0.07 \text{ Btu/hr-ft}^2 \text{ (} ^\circ\text{F/ft)} \end{aligned}$$

$$N_{Nu} = \frac{(200)(1.5/12)}{0.07} = 357.1$$

SI units

$$\begin{aligned} h &= (200)(5.678) \text{ J/(s-m}^2\text{-}^\circ\text{C)} \\ D &= (1.5)(0.0254) \text{ m} \\ k &= (0.07)(1.728) \text{ J/s-m}^2 \text{ (} ^\circ\text{C/m)} \end{aligned}$$

$$N_{Nu} = \frac{(200)(5.678)(1.5)(0.0254)}{(0.07)(1.728)} = 357.7$$

(Difference due to rounding)

Example 4. Calculation of a Grashof Number

$$N_{Gr} = L^3\rho^2g\beta(\Delta T)/\mu^2$$

U.S. Customary units

$$\begin{aligned} L &= 3 \text{ ft} \\ \rho &= 0.0725 \text{ lbm/ft}^3 \\ g &= 32.174 \text{ ft/s}^2 \\ \beta &= 0.00168/^\circ\text{R} \\ \Delta T &= 99 \text{ } ^\circ\text{R} \\ \mu &= 0.019 \text{ centipoise} = 0.019 \times 0.000672 \text{ lbm/ft-s} \\ &= 1.277 \times 10^{-5} \text{ lbm/ft-s} \end{aligned}$$

$$N_{Gr} = \frac{(3^3)(0.0725)^2(32.174)(0.00168)(99)}{(1.277 \times 10^{-5})^2} = 4.66 \times 10^9$$

SI units

$$\begin{aligned} L &= (3)(0.3048) = 0.9144 \text{ m} \\ \rho &= (0.0725)(16.018) = 1.1613 \text{ kg/m}^3 \\ g &= 9.807 \text{ m/s}^2 \\ \beta &= (0.00168)/(1.8) = 0.000933/^\circ\text{K} \\ \Delta T &= (99)(1.8) = 178.2 \text{ } ^\circ\text{K} \\ \mu &= (0.019)(0.001) = 1.9 \times 10^{-5} \text{ kg/m-s} \end{aligned}$$

$$N_{Gr} = \frac{(0.9144)^3(1.1613)^2(9.807)(0.000933)(178.2)}{(1.9 \times 10^{-5})^2} = 4.66 \times 10^9$$

Example 5. Calculation of a Schmidt Number

$$N_{Sc} = \frac{\mu}{\rho D}$$

U.S. customary units

$$\begin{aligned} \mu &= 0.02 \text{ centipoise} = (0.02)(2.42) \text{ lbm/ft-hr} \\ \rho &= 0.08 \text{ lbm/ft}^3 \\ D &= 1.0 \text{ ft}^2/\text{hr (diffusivity)} \end{aligned}$$

$$N_{Sc} = \frac{(0.02)(2.42)}{(0.08)(1.0)} = 0.605$$

SI units

$$\begin{aligned} \mu &= (0.02)(0.001) \text{ kg/m-s} \\ \rho &= (0.08)(16.02) \text{ kg/m}^3 \\ D &= (1.0)(2.58 \times 10^{-9}) \text{ m}^2/\text{s} \end{aligned}$$

$$N_{Sc} = \frac{(0.02)(0.001)}{(0.08)(16.02)(1.0)(2.58 \times 10^{-9})} = 0.605$$

Example 6. Calculation of an Archimedes Number

$$N_{Ar} = \frac{d^3\rho(\rho_p - \rho)g}{\mu^2}$$

U.S. customary units

$$\begin{aligned} d &= 2 \text{ mm} = 2/[(1000)(0.3048)] = 0.00656 \text{ ft} \\ \rho_f &= 0.0175 \text{ lbm/ft}^3 \\ \rho_p &= 168.5 \text{ lbm/ft}^3 \\ g &= 32.174 \text{ ft/s}^2 \\ \mu &= 0.04 \text{ centipoise} = 0.04 \times 0.000672 = 2.688 \times 10^{-5} \text{ lbm/ft-s} \end{aligned}$$

$$N_{Ar} = \frac{(0.00656)^3(0.0175)(168.5 - 0.0175)(32.174)}{(2.688 \times 10^{-5})^2} = 37,064$$

SI units

$$\begin{aligned} d &= 2/1000 \text{ m} \\ \rho_f &= 168.5 \times 16.02 = 2699.37 \text{ kg/m}^3 \\ \rho_p &= 0.0175 \times 16.02 = 0.2804 \text{ g/m}^3 \\ g &= 9.807 \text{ m/s}^2 \\ \mu &= 0.04 \times 0.001 = 4 \times 10^{-5} \text{ kg/m-s} \end{aligned}$$

$$N_{Ar} = \frac{(2/1000)^3(0.2804)(2699.37 - 0.28)(9.807)}{(4 \times 10^{-5})^2} = 37,118$$

(Difference due to rounding)

MATHEMATICAL SYMBOLS

TABLE 1-15 Mathematical Signs, Symbols, and Abbreviations

\pm (\mp)	plus or minus (minus or plus)
:	divided by, ratio sign
::	proportional sign
<	less than
\nless	not less than
>	greater than
\ngtr	not greater than
\approx	approximately equals, congruent
\sim	similar to
\doteq	equivalent to
\neq	not equal to
\doteq	approaches, is approximately equal to
∞	varies as
∞	infinity
\therefore	therefore
$\sqrt{\quad}$	square root
$\sqrt[3]{\quad}$	cube root
$\sqrt[n]{\quad}$	<i>n</i> th root
\angle	angle
\perp	perpendicular to
\parallel	parallel to
<i>x</i>	numerical value of <i>x</i>
log or log ₁₀	common logarithm or Briggsian logarithm
log _e or ln	natural logarithm or hyperbolic logarithm or Napierian logarithm
<i>e</i>	base (2.178) of natural system of logarithms
<i>a</i> °	an angle <i>a</i> degrees
<i>a'</i> <i>a</i>	prime, an angle <i>a</i> minutes
<i>a''</i> <i>a</i>	double prime, an angle <i>a</i> seconds, <i>a</i> second
sin	sine
cos	cosine
tan	tangent
ctn or cot	cotangent
sec	secant
csc	cosecant
vers	versed sine
covers	covered sine
exsec	exsecant
sin ⁻¹	anti sine or angle whose sine is
sinh	hyperbolic sine
cosh	hyperbolic cosine
tanh	hyperbolic tangent
sinh ⁻¹	anti hyperbolic sine or angle whose hyperbolic sine is
<i>f</i> (<i>x</i>) or ϕ (<i>x</i>)	function of <i>x</i>
Δx	increment of <i>x</i>
Σ	summation of
<i>dx</i>	differential of <i>x</i>
<i>dy/dx</i> or <i>y'</i>	derivative of <i>y</i> with respect to <i>x</i>
<i>d</i> ² <i>y/dx</i> ² or <i>y''</i>	second derivative of <i>y</i> with respect to <i>x</i>
<i>d</i> ^{<i>n</i>} <i>y/dx</i> ^{<i>n</i>}	<i>n</i> th derivative of <i>y</i> with respect to <i>x</i>
$\partial y/\partial x$	partial derivative of <i>y</i> with respect to <i>x</i>
$\partial^n y/\partial x^n$	<i>n</i> th partial derivative of <i>y</i> with respect to <i>x</i>
$\frac{\partial^n y}{\partial x \partial y}$	<i>n</i> th partial derivative with respect to <i>x</i> and <i>y</i>
\int	integral of
\int_a^b	integral between the limits <i>a</i> and <i>b</i>
\dot{y}	first derivative of <i>y</i> with respect to time
\ddot{y}	second derivative of <i>y</i> with respect to time
Δ or ∇^2	the "Laplacian"
$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right)$	
δ	sign of a variation
\oint	sign for integration around a closed path

TABLE 1-16 Greek Alphabet

Alpha	= A, α = A, a	Nu	= N, ν = N, n
Beta	= B, β = B, b	Xi	= Ξ, ξ = X, x
Gamma	= Γ, γ = G, g	Omicron	= O, ο = O, o
Delta	= Δ, δ = D, d	Pi	= Π, π = P, p
Epsilon	= Ε, ε = E, e	Rho	= Ρ, ρ = R, r
Zeta	= Ζ, ζ = Z, z	Sigma	= Σ, σ = S, s
Eta	= Η, η = E, e	Tau	= Τ, τ = T, t
Theta	= Θ, θ = Th, th	Upsilon	= Υ, υ = U, u
Iota	= Ι, ι = I, i	Phi	= Φ, φ = Ph, ph
Kappa	= Κ, κ = K, k	Chi	= Χ, χ = Ch, ch
Lambda	= Λ, λ = L, l	Psi	= Ψ, ψ = Ps, ps
Mu	= Μ, μ = M, m	Omega	= Ω, ω = O, o