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STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS

H. Wayne Beaty • Donald G. Fink

Mc Graw Hill

STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS

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STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS

H. Wayne Beaty Editor

Donald G. Fink (Deceased) Editor

SIXTEENTH EDITION



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CONTENTS

Contributors ix
Preface xiii
Acknowledgment xv

Section 1. Units, Symbols, Constants, Definitions, and Conversion Factors *Donald G. Fink and H. Wayne Beaty* 1.1

Section 2. Electric and Magnetic Circuits *Paulo F. Ribeiro and Xiuhua Si* 2.1

Section 3. Measurements and Instruments *Donald G. Fink* 3.1

Section 4. Properties of Materials *Glenn Davidson and Philip Mason Opsal* 4.1

Section 5. Generation *Allen L. Clapp, Stephen O. Dean, and George H. Miley* 5.1

Section 6. Prime Movers 6.1

Section 7. Alternating-Current Generators *Erik Abromitis, Samuel A. Drinkut, Franklin T. Emery, and Om P. Malik* 7.1

Section 8. Direct-Current Generators *O. A. Mohammed* 8.1

Section 9. Hydroelectric Power Generation *U.S. Army Corps of Engineers* 9.1

Section 10. Power System Components *Craig A. Colopy, Carey J. Cook, Jon Hilgenkamp, David S. Johnson, Christopher McCarthy, Mark McVey, Jeffrey H. Nelson, T. W. Olsen, Douglas M. Staszesky, and Michael W. Wactor* 10.1

Section 11. Alternate Sources of Power *Ramesh Bansal, Thomas G. Benjamin, Paul C. Butler, Mario Mañana Canteli, Palmer W. Carlin, Jim Eyer, Haresh Kamath, John P. Kopasz, Michael R. Milligan, Neil B. Morley, Walter F. Podolski, Lisa A. Shevenell, Karin Sinclair, Heidi Crevison Souder, Robert Thresher, Mark S. Tillack, Yih-Huei Wan, Robert D. Weaver, and Ahmed F. Zobaa* 11.1

Section 12. Electric Power System Economics *Gerald B. Sheblé* 12.1

Section 13. Project Economics *Allen L. Clapp* 13.1

Section 14. Transmission Systems *Earle C. (Rusty) Bascom III, Allen L. Clapp, Jose R. Daconti, Dale A. Douglass, A. M. DiGioia, Jr., I. S. Grant, Otto L. Lynch, John D. Mozer, and J. R. Stewart* 14.1

Section 15. High-Voltage Direct-Current Power Transmission *Ram Adapa* 15.1

Section 16. Power System Operations *John Adams, Hassan Bevrani, Math H. J. Bollen, Gustavo Brunello, Rujiroj Leelaruji, Christopher McCarthy, Yasunori Mitani, Sarma Nuthalapati, Oladiran Obadina, Paulo F. Ribeiro, Hesham Shaalan, Douglas M. Staszesky, George R. Stoll, Resmi Surendran, Luigi Vanfretti, and Masauki Watanabe* 16.1

Section 17. Substations *John Randolph, Philip C. Bolin, and Allen L. Clapp* 17.1

Section 18. Power Distribution *Allen L. Clapp, Daniel J. Ward, and Cheryl A. Warren* 18.1

Section 19. Wiring Design for Commercial and Industrial Buildings *John Dagenhart* 19.1

Section 20. Motors and Drives *Om P. Malik* 20.1

Section 21. Industrial and Commercial Applications of Electric Power *Hesham Shaalan* 21.1

Section 22. Power Electronics *Amit Kumar Jain and Raja Ayyanar* 22.1

Section 23. Power Quality and Reliability *Surya Santoso, Mark F. McGranaghan, and Roger C. Dugan* 23.1

Section 24. Grounding/Earthing Systems *David R. Stockin, Michael A. Esparza, and Jeffrey D. Drummond* 24.1

Section 25. Computer Applications in the Electric Power Industry *Juan A. Martinez-Velasco* 25.1

Section 26. Illumination *Kyle Hemmi* 26.1

Section 27. Lightning and Overvoltage Protection *A. P. (Sakis) Meliopoulos* 27.1

Section 28. Standards in Electrotechnology, Telecommunications, and Information Technology
Marco W. Migliaro 28.1

Index follows Section 28

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PREFACE

The aims of this Sixteenth Edition are the same as those of prior editions, namely, to contain in a single volume all pertinent electrical engineering data, to be accurate and comprehensive in a technical treatment, to be of use in engineering practice (as well as in study and preparation for such practice), and, above all, to be oriented toward practical application, including the impact of economic considerations.

Electrical engineering generally deals with the study and application of electricity, electronics, and electromagnetism. It first became an identifiable occupation in the late nineteenth century after commercialization of the electric telegraph and electrical power supply. It now covers a range of subtopics including power, electronics, control systems, signal processing, and telecommunications.

This handbook deals with the whole range of electrical engineering, including generation, transmission, and distribution of electricity as well as the design of a range of related devices, including transformers, electric generators, electric motors, high-voltage engineering, and power electronics.

Coal currently provides 40 percent of the world's electricity needs. It is the second source of primary energy in the world after oil, and the first source of electricity generation. The environmental impact of coal use, especially that coming from carbon dioxide emissions, is still a problem for electricity generation. Despite positive efforts building more-efficient plants, retrofitting old plants, and decommissioning the oldest, least-efficient plants, environmental regulations are a hindrance to more coal-fired generation.

Nuclear fission has been in use for more than 50 years. However, important barriers to an expansion of nuclear energy remain. Governments will need to set clear and consistent policies on nuclear energy to encourage private sector investment. Gaining greater public acceptance will also be a key component of nuclear energy, and this will be helped by early implementation of plans for geological disposal of radioactive waste, as well as continued safe and effective operation of nuclear plants. Japan's first commercial nuclear power reactor began operating in mid-1966, and nuclear energy has been a national strategic priority since 1973. This is now under review following the 2011 Fukushima accident.

Energy conservation and efficient energy use will continue to be of concern to engineers. New techniques and technologies that enhance both supply-side and demand-side energy management will need to be developed and implemented.

Alternate energy sources such as wind power, solar power, geothermal power, magnetohydrodynamics, nuclear fusion, storage systems, and fuel cells are still being developed and implemented. However, some of these technologies require governmental subsidies to become viable options. The U.S. Department of Energy reports that "in 2011, the global market for clean, renewable energies reached a record $260 billion—and is expected to grow into the trillions over the next 20 years. Solar manufacturing in particular is growing dramatically in the United States and around the world. In fact, according to the Solar Energy Industry Association, America's solar industry now employs 100,000 workers—doubling since 2009."

H. Wayne Beaty

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The editor would like to acknowledge the contributions and authorships of more than 75 national and international experts in the electrical engineering field. Contributors to this edition of the handbook are from academia as well as practicing engineers. It is a joy and privilege to work with such gifted people. Your comments and suggestions on how to improve the handbook are most welcome.

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STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS

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1

UNITS, SYMBOLS, CONSTANTS, DEFINITIONS, AND CONVERSION FACTORS

Donald G. Fink

An Editor of this Handbook until his death in 1996

H. Wayne Beaty

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1.1 THE SI UNITS 1.1
1.2 CGPM BASE QUANTITIES 1.2
1.3 SUPPLEMENTARY SI UNITS 1.3
1.4 DERIVED SI UNITS 1.3
1.5 SI DECIMAL PREFIXES 1.5
1.6 USAGE OF SI UNITS, SYMBOLS, AND PREFIXES 1.5
1.7 OTHER SI UNITS 1.7
1.8 CGS SYSTEMS OF UNITS 1.8
1.9 PRACTICAL UNITS (ISU) 1.8
1.10 DEFINITIONS OF ELECTRICAL QUANTITIES 1.9
1.11 DEFINITIONS OF QUANTITIES OF RADIATION AND LIGHT 1.13
1.12 LETTER SYMBOLS 1.15
1.13 GRAPHIC SYMBOLS 1.26
1.14 PHYSICAL CONSTANTS 1.26
1.15 NUMERICAL VALUES 1.32
1.16 CONVERSION FACTORS 1.32
1.17 BIBLIOGRAPHY 1.56
1.17.1 Standards 1.56
1.17.2 Collections of Units and Conversion Factors 1.57
1.17.3 Books and Papers 1.57

1.1 THE SI UNITS

The units of the quantities most commonly used in electrical engineering (volts, amperes, watts, ohms, etc.) are those of the metric system. They are embodied in the International System of Units (*Système International d'Unités*, abbreviated *SI*). The SI units are used throughout this handbook, in accordance with the established practice of electrical engineering publications throughout the world. Other units, notably the cgs (centimeter-gram-second) units, may have been used in citations in the earlier literature. The cgs electrical units are listed in Table 1-9 with conversion factors to the SI units.

The SI electrical units are based on the mksa (meter-kilogram-second-ampere) system. They have been adopted by the standardization bodies of the world, including the International Electrotechnical Commission (IEC), the American National Standards Institute (ANSI), and the Standards Board of the Institute of Electrical and Electronics Engineers (IEEE). The United States is the only industrialized nation in the world that does not mandate the use of the SI system. Although the U.S. Congress has the constitutional right to establish measuring units, it has never enforced any system. The metric system (now SI) was legalized by Congress in 1866 and is the only legal measuring system, but other non-SI units are legal as well.

Other English-speaking countries adopted the SI system in the 1960s and 1970s. A few major industries converted, but many people resisted—some for very irrational reasons, denouncing it as "un-American." Progressive businesses and educational institutions urged Congress to mandate SI. As a result, in the 1988 Omnibus Trade and Competitiveness Act, Congress established SI as the *preferred* system for U.S. trade and commerce and urged all federal agencies to adopt it by the end of 1992 (or as quickly as possible without undue hardship). SI remains voluntary for private U.S. business. An excellent book, *Metric in Minutes* (Brownridge, 1994), is a comprehensive resource for learning and teaching the metric system (SI).

1.2 CGPM BASE QUANTITIES

Seven quantities have been adopted by the General Conference on Weights and Measures (CGPM[†]) as *base quantities*, that is, quantities that are not derived from other quantities. The base quantities are length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity. Table 1-1 lists these quantities, the name of the SI unit for each, and the standard letter symbol by which each is expressed in the International System (SI).

TABLE 1-1 SI Base Units

Quantity	Unit	Symbol
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

*Celsius temperature is, in general, expressed in degrees Celsius (symbol °C).

The units of the base quantities have been defined by the CGPM as follows:

Meter. The length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $^2p_{10}$ and $^5d_5$ of the krypton-86 atom (CGPM).

Kilogram. The unit of mass; it is equal to the mass of the international prototype of the kilogram (CGPM).

EDITOR'S NOTE: The prototype is a platinum-iridium cylinder maintained at the International Bureau of Weights and Measures, near Paris. The kilogram is approximately equal to the mass of 1000 cubic centimeters of water at its temperature of maximum density.

Second. The duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium = 133 atoms (CGPM).

Ampere. The constant current that if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 meter apart in vacuum would produce between these conductors a force equal to 2×10^{-7} newton per meter of length (CGPM).

Kelvin. The unit of thermodynamic temperature is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water (CGPM).

EDITOR'S NOTE: The zero of the Celsius scale (the freezing point of water) is defined as 0.01 K below the triple point, that is, 273.15 K. See Table 1-27.

[†]From the initials of its French name, *Conference Générale des Poids et Mesures.*

Mole. That amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12 (CGPM).

NOTE: 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.

Candela. The luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz and that has a radiant intensity in that direction of 1/683 watt per steradian (CGPM).

EDITOR'S NOTE: Until January 1, 1948, the generally accepted unit of luminous intensity was the *international candle*. The difference between the candela and the international candle is so small that only measurements of high precision are affected. The use of the term *candle* is deprecated.

1.3 SUPPLEMENTARY SI UNITS

Two additional SI units, numerics which are considered as dimensionless derived units (see Sec. 1.4), are the radian and the steradian, for the quantities plane angle and solid angle, respectively. Table 1-2 lists these quantities and their units and symbols. The supplementary units are defined as follows:

TABLE 1-2 SI Supplementary Units

Quantity	Unit	Symbol
Plane angle	radian	rad
Solid angle	steradian	sr

Radian. The plane angle between two radii of a circle that cut off on the circumference an arc equal in length to the radius (CGPM).

Steradian. The solid angle which, having its vertex in the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square with sides equal to the radius of the sphere (CGPM).

1.4 DERIVED SI UNITS

Most of the quantities and units used in electrical engineering fall in the category of SI derived units, that is, units which can be completely defined in terms of the base and supplementary quantities described above. Table 1-3 lists the principal electrical quantities in the SI system and shows their equivalents in terms of the base and supplementary units. The definitions of these quantities, as they appear in the *IEEE Standard Dictionary of Electrical and Electronics Terms* (ANSI/IEEE Std 100-1988), are

Hertz. The unit of frequency 1 cycle per second.

Newton. The force that will impart an acceleration of 1 meter per second to a mass of 1 kilogram.

Pascal. The pressure exerted by a force of 1 newton uniformly distributed on a surface of 1 square meter.

Joule. The work done by a force of 1 newton acting through a distance of 1 meter.

Watt. The power required to do work at the rate of 1 joule per second.

Coulomb. The quantity of electric charge that passes any cross section of a conductor in 1 second when the current is maintained constant at 1 ampere.

Volt. The potential difference between two points of a conducting wire carrying a constant current of 1 ampere, when the power dissipated between these points is 1 watt.

Farad. The capacitance of a capacitor in which a charge of 1 coulomb produces 1 volt potential difference between its terminals.

Ohm. The resistance of a conductor such that a constant current of 1 ampere in it produces a voltage of 1 volt between its ends.

TABLE 1-3 SI Derived Units in Electrical Engineering

Quantity	SI unit			
	Name	Symbol	Expression in terms of other units	Expression in terms of SI base units
Frequency (of a periodic phenomenon)	hertz	Hz	1/s	s^{-1}
Force	newton	N		$m \cdot kg \cdot s^{-2}$
Pressure, stress	pascal	Pa	N/m^2	$m^{-1} \cdot kg \cdot s^{-2}$
Energy, work, quantity of heat	joule	J	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
Power, radiant flux	watt	W	J/s	$m^2 \cdot kg \cdot s^{-3}$
Quantity of electricity, electric charge	coulomb	C	$A \cdot s$	$s \cdot A$
Potential difference, electric potential, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
Electric capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
Electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
Conductance	siemens	S	A/V	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
Magnetic flux	weber	Wb	$V \cdot s$	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
Magnetic flux density	tesla	T	Wb/m^2	$kg \cdot s^{-2} \cdot A^{-1}$
Celsius temperature	degree Celsius	°C	K	
Inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Luminous flux	lumen	lm		$cd \cdot sr*$
Illuminance	lux	lx	lm/m^2	$m^{-2} \cdot cd \cdot sr*$
Activity (of radionuclides)	becquerel	Bq	I/s	s^{-1}
Absorbed dose	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
Dose equivalent	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$

*In this expression, the steradian (sr) is treated as a base unit. See Table 1-2.

Siemens (mho). The conductance of a conductor such that a constant voltage of 1 volt between its ends produces a current of 1 ampere in it.

Weber. The magnetic flux whose decrease to zero when linked with a single turn induces in the turn a voltage whose time integral is 1 volt-second.

Tesla. The magnetic induction equal to 1 weber per square meter.

Henry. The inductance for which the induced voltage in volts is numerically equal to the rate of change of current in amperes per second.

TABLE 1-4 Examples of SI Derived Units of General Application in Engineering

Quantity	SI unit	
	Name	Symbol
Angular velocity	radian per second	rad/s
Angular acceleration	radian per second squared	rad/s^2
Radiant intensity	watt per steradian	W/sr
Radiance	watt per square meter steradian	$W \cdot m^{-2} \cdot sr^{-1}$
Area	square meter	m^2
Volume	cubic meter	m^3
Velocity	meter per second	m/s
Acceleration	meter per second squared	m/s^2
Wavenumber	1 per meter	m^{-1}
Density, mass	kilogram per cubic meter	kg/m^3
Concentration (of amount of substance)	mole per cubic meter	mol/m^3
Specific volume	cubic meter per kilogram	m^3/kg
Luminance	candela per square meter	cd/m^2

TABLE 1-5 Examples of SI Derived Units Used in Mechanics, Heat, and Electricity

	SI unit		
Quantity	Name	Symbol	Expression in terms of SI base units
Viscosity, dynamic	pascal second	Pa · s	$m^{-1} \cdot kg \cdot s^{-1}$
Moment of force	newton meter	N · m	$m^2 \cdot kg \cdot s^{-2}$
Surface tension	newton per meter	N/m	$kg \cdot s^{-2}$
Heat flux density, irradiance	watt per square meter	W/m^2	$kg \cdot s^{-3}$
Heat capacity	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
Specific heat capacity, specific entropy	joule per kilogram kelvin	J/(kg · K)	$m^2 \cdot s^{-2} \cdot K^{-1}$
Specific energy	joule per kilogram	J/kg	$m^2 \cdot s^{-2}$
Thermal conductivity	watt per meter kelvin	W/(m · K)	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
Energy density	joule per cubic meter	J/m^3	$m^{-1} \cdot kg \cdot s^{-2}$
Electric field strength	volt per meter	V/m	$m \cdot kg \cdot s^{-3} \cdot A^{-1}$
Electric charge density	coulomb per cubic meter	C/m^3	$m^{-3} \cdot s \cdot A$
Electric flux density	coulomb per square meter	C/m^2	$m^{-2} \cdot s \cdot A$
Permittivity	farad per meter	F/m	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
Current density	ampere per square meter	A/m^2	
Magnetic field strength	ampere per meter	A/m	
Permeability	henry per meter	H/m	$m \cdot kg \cdot s^{-2} \cdot A^{-2}$
Molar energy	joule per mole	J/mol	$m^2 \cdot kg \cdot s^{-2} \cdot mol^{-1}$
Molar entropy, molar heat capacity	joule per mole kelvin	J/(mol · K)	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} mol^{-1}$

Lumen. The flux through a unit solid angle (steradian) from a uniform point source of 1 candela; the flux on a unit surface all points of which are at a unit distance from a uniform point source of 1 candela.

Lux. The illumination on a surface of 1 square meter on which there is uniformly distributed a flux of 1 lumen; the illumination produced at a surface all points of which are 1 meter away from a uniform point source of 1 candela.

Table 1-4 lists other quantities and the SI derived unit names and symbols useful in engineering applications. Table 1-5 lists additional quantities and the SI derived units and symbols used in mechanics, heat, and electricity.

1.5 SI DECIMAL PREFIXES

All SI units may have affixed to them standard prefixes which multiply the indicated quantity by a power of 10. Table 1-6 lists the standard prefixes and their symbols. A substantial part of the extensive range (10^{36}) covered by these prefixes is in common use in electrical engineering (e.g., gigawatt, gigahertz, nanosecond, and picofarad). The practice of compounding a prefix (e.g., micromicrofarad) is deprecated (the correct term is picofarad).

1.6 USAGE OF SI UNITS, SYMBOLS, AND PREFIXES

Care must be exercised in using the SI symbols and prefixes to follow exactly the capital-letter and lowercase-letter usage prescribed in Tables 1-1 through 1-8, inclusive. Otherwise, serious confusion may occur. For example, pA is the SI symbol for 10^{-12} of the SI unit for electric current (picoampere), while Pa is the SI symbol for pressure (the pascal).

TABLE 1-6 SI Prefixes Expressing Decimal Factors

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

The spelled-out names of the SI units (e.g., volt, ampere, watt) are not capitalized. The SI letter symbols are capitalized only when the name of the unit stands for or is directly derived from the name of a person. Examples are V for volt, after Italian physicist Alessandro Volta (1745–1827); A for ampere, after French physicist André-Marie Ampère (1775–1836); and W for watt, after Scottish engineer James Watt (1736–1819). The letter symbols serve the function of abbreviations, but they are used without periods.

It will be noted from Tables 1-1, 1-3, and 1-5 that with the exception of the ampere, all the SI electrical quantities and units are derived from the SI base and supplementary units or from other SI derived units. Thus, many of the short names of SI units may be expressed in compound form embracing the SI units from which they are derived. Examples are the volt per ampere for the ohm, the joule per second for the watt, the ampere-second for the coulomb, and the watt-second for the joule. Such compound usage is permissible, but in engineering publications, the short names are customarily used.

Use of the SI prefixes with non-SI units is not recommended; the only exception stated in IEEE Standard 268 is the microinch. Non-SI units, which are related to the metric system but are not decimal multiples of the SI units such as the calorie, torr, and kilogram-force, are specially to be avoided.

TABLE 1-7 Time and Angle Units Used in the SI System (Not Decimally Related to the SI Units)

Name	Symbol	Value in SI unit
minute	min	1 min = 60 s
hour	h	1 h = 60 min = 3 600 s
day	d	1 d = 24 h = 86 400 s
degree	°	$1° = (\pi/180)$ rad
minute	′	$1′ = (1/60)° = (\pi/10\,800)$ rad
second	″	$1″ = (1/60)′ = (\pi/648\,000)$ rad

A particular problem arises with the universally used units of time (minute, hour, day, year, etc.) that are nondecimal multiples of the second. Table 1-7 lists these and their equivalents in seconds, as well as their standard symbols (see also Table 1-19). The watthour (Wh) is a case in point; it is equal to 3600 joules. The kilowatthour (kWh) is equal to 3 600 000 joules or 3.6 megajoules (MJ). In the mid-1980s, the use of the kilowatthour persisted widely, although eventually it was expected to be replaced by the megajoule, with the conversion factor 3.6 megajoules per kilowatthour. Other aspects in the usage of the SI system are the subject of the following recommendations published by the IEEE:

Frequency. The CGPM has adopted the name *hertz* for the unit of frequency, but cycle per second is widely used. Although cycle per second is technically correct, the name *hertz* is preferred because of the widespread use of cycle alone as a unit of frequency. Use of cycle in place of cycle per second, or kilocycle in place of kilocycle per second, etc., is incorrect.

Magnetic Flux Density. The CGPM has adopted the name *tesla* for the SI unit of magnetic flux density. The name *gamma* shall not be used for the unit nanotesla.

Temperature Scale. In 1948, the CGPM abandoned *centigrade* as the name of the temperature scale. The corresponding scale is now properly named the *Celsius scale*, and further use of *centigrade* for this purpose is deprecated.

Luminous Intensity. The SI unit of luminous intensity has been given the name *candela*, and further use of the old name *candle* is deprecated. Use of the term *candle-power*, either as the name of a quantity or as the name of a unit, is deprecated.

Luminous Flux Density. The common British-American unit of luminous flux density is the lumen per square foot. The name *footcandle*, which has been used for this unit in the United States, is deprecated.

Micrometer and Micron. The names *micron* for micrometer and *millimicron* for nanometer are deprecated.

Gigaelectronvolt (GeV). Because billion means a thousand million in the United States but a million million in most other countries, its use should be avoided in technical writing. The term *billion electronvolts* is deprecated; use gigaelectronvolts instead.

British-American Units. In principle, the number of British-American units in use should be reduced as rapidly as possible. Quantities are not to be expressed in mixed units. For example, mass should be expressed as 12.75 lb, rather than 12 lb or 12 oz. As a start toward implementing this recommendation, the following should be abandoned:

1. British thermal unit (for conversion factors, see Table 1-25).
2. horsepower (see Table 1-26).
3. Rankine temperature scale (see Table 1-27).
4. U.S. dry quart, U.S. liquid quart, and U.K. (Imperial) quart, together with their various multiples and subdivisions. If it is absolutely necessary to express volume in British-American units, the cubic inch or cubic foot should be used (for conversion factors, see Table 1-17).
5. footlambert. If it is absolutely necessary to express luminance in British-American units, the candela per square foot or lumen per steradian square foot should be used (see Table 1-28A).
6. inch of mercury (see Table 1-23C).

1.7 OTHER SI UNITS

Table 1-8 lists units used in the SI system whose values are not derived from the base quantities but from experiment. The definitions of these units, given in the *IEEE Standard Dictionary* (ANSI/IEEE Std 100-1988) are

Electronvolt. The kinetic energy acquired by an electron in passing through a potential difference of 1 volt in vacuum.

NOTE: The electronvolt is equal to 1.60218×10^{-19} joule, approximately (see Table 1-25B).

Unified Atomic Mass Unit. The fraction ½ of the mass of an atom of the nuclide ^{12}C.

NOTE: u is equal to $1.660\,54 \times 10^{-27}$ kg, approximately.

Astronomical Unit. The length of the radius of the unperturbed circular orbit of a body of negligible mass moving around the sun with a sidereal angular velocity of 0.017 202 098 950 radian per day of 86 400 ephemeris seconds.

NOTE: The International Astronomical Union has adopted a value for 1 AU equal to 1.496×10^{11} meters (see Table 1-15C).

Parsec. The distance at which 1 astronomical unit subtends an angle of 1 second of arc. 1 pc = 206 264.8 AU = $30\,857 \times 10^{12}$ m, approximately (see Table 1-15C).

TABLE 1-8 Units Used with the SI System Whose Values Are Obtained Experimentally

Name	Symbol
electronvolt	eV
unified atomic mass unit	u
astronomical unit*	
parsec	pc

*The astronomical unit does not have an international symbol. AU is customarily used in English, UA in French.

1.8 CGS SYSTEMS OF UNITS

The units most commonly used in physics and electrical science, from their establishment in 1873 until their virtual abandonment in 1948, are based on the centimeter-gram-second (cgs) electromagnetic and electrostatic systems. They have been used primarily in theoretical work, as contrasted with the SI units (and their "practical unit" predecessors, see Sec. 1.9) used in engineering. Table 1-9 lists the principal cgs electrical quantities and their units, symbols, and equivalent values in SI units. Use of these units in electrical engineering publications has been officially deprecated by the IEEE since 1966.

The cgs units have not been used to any great extent in electrical engineering, since many of the units are of inconvenient size compared with quantities used in practice. For example, the cgs electromagnetic unit of capacitance is the gigafarad.

1.9 PRACTICAL UNITS (ISU)

The shortcomings of the cgs systems were overcome by adopting the volt, ampere, ohm, farad, coulomb, henry, joule, and watt as "practical units," each being an exact decimal multiple of the corresponding electromagnetic cgs unit (see Table 1-9). From 1908 to 1948, the practical electrical units were embodied in the International System Units (ISU, not to be confused with the SI units). During these years, precise formulation of the units in terms of mass, length, and time was impractical because of imprecision in the measurements of the three basic quantities. As an alternative, the units were standardized by comparison with apparatus, called *prototype standards.* By 1948, advances in the measurement of the basic quantities permitted precise standardization by reference to the definitions of the basic units, and the International System Units were officially abandoned in favor of the absolute units. These in turn were supplanted by the SI units which came into force in 1950.

TABLE 1-9 CGS Units and Equivalents

Quantity	Name	Symbol	Correspondence with SI unit
	Electromagnetic system		
Current	abampere	abA	= 10 amperes (exactly)
Voltage	abvolt	abV	= 10^{-8} volt (exactly)
Capacitance	abfarad	abF	= 10^{9} farads (exactly)
Inductance	abhenry	abH	= 10^{-9} henry (exactly)
Resistance	abohm	abΩ	= 10^{-9} ohm (exactly)
Magnetic flux	maxwell	Mx	= 10^{-8} weber (exactly)
Magnetic field strength	oersted	Oe	= 79.577 4 amperes per meter
Magnetic flux density	gauss	G	= 10^{-4} tesla (exactly)
Magnetomotive force	gilbert	Gb	= 0.795 774 ampere
	Electrostatic system		
Current	statampere	statA	= $3.335\,641 \times 10^{-10}$ ampere
Voltage	statvolt	statV	= 299.792 46 volts
Capacitance	statfarad	statF	= $1.112\,650 \times 10^{-12}$ farad
Inductance	stathenry	statH	= $8.987\,554 \times 10^{11}$ henrys
Resistance	statohm	statΩ	= $8.987\,554 \times 10^{11}$ ohms
	Mechanical units		
	(equally applicable to the electrostatic and electromagnetic systems)		
Work/energy	erg	erg	= 10^{-7} joule (exactly)
Force	dyne	dyn	= 10^{-5} newton (exactly)

1.10 DEFINITIONS OF ELECTRICAL QUANTITIES

The following definitions are based on the principal meanings listed in the *IEEE Standard Dictionary* (ANSI/IEEE Std 100-1988), which should be consulted for extended meanings, compound terms, and related definitions. The United States Standard Symbols (ANSI/IEEE Std 260, IEEE Std 280) for these quantities are shown in parentheses (see also Tables 1-10 and 1-11). Electrical units used in the United States prior to 1969, with SI equivalents, are listed in Table 1-29.

Admittance (Y). An admittance of a linear constant-parameter system is the ratio of the phasor equivalent of the steady-state sine-wave current or current-like quantity (response) to the phasor equivalent of the corresponding voltage or voltage-like quantity (driving force).

Capacitance (C). Capacitance is that property of a system of conductors and dielectrics which permits the storage of electrically separated charges when potential differences exist between the conductors. Its value is expressed as the ratio of an electric charge to a potential difference.

Coupling Coefficient (k). Coefficient of coupling (used only in the case of resistive, capacitive, and inductive coupling) is the ratio of the mutual impedance of the coupling to the square root of the product of the self-impedances of similar elements in the two circuit loops considered. Unless otherwise specified, coefficient of coupling refers to inductive coupling, in which case $k = M/(L_1L_2)^{1/2}$, where M is the mutual inductance, L_1 the self-inductance of one loop, and L_2 the self-inductance of the other.

Conductance (G)

1. The conductance of an element, device, branch, network, or system is the factor by which the mean-square voltage must be multiplied to give the corresponding power lost by dissipation as heat or as other permanent radiation or as electromagnetic energy from the circuit.
2. Conductance is the real part of admittance.

Conductivity (γ). The conductivity of a material is a factor such that the conduction current density is equal to the electric field strength in the material multiplied by the conductivity.

Current (I). Current is a generic term used when there is no danger of ambiguity to refer to any one or more of the currents described below. (For example, in the expression "the current in a simple series circuit," the word *current* refers to the conduction current in the wire of the inductor and to the displacement current between the plates of the capacitor.)

Conduction Current. The conduction current through any surface is the integral of the normal component of the conduction current density over that surface.

Displacement Current. The displacement current through any surface is the integral of the normal component of the displacement current density over that surface.

Current Density (J). Current density is a generic term used when there is no danger of ambiguity to refer either to conduction current density or to displacement current density or to both.

Displacement Current Density. The displacement current density at any point in an electric field is (in the International System) the time rate of change of the electric-flux-density vector at that point.

Conduction Current Density. The electric conduction current density at any point at which there is a motion of electric charge is a vector quantity whose direction is that of the flow of positive charge at this point, and whose magnitude is the limit of the time rate of flow of net (positive) charge across a small plane area perpendicular to the motion, divided by this area, as the area taken approaches zero in a macroscopic sense, so as to always include this point. The flow of charge may result from the movement of free electrons or ions but is not in general, except in microscopic studies, taken to include motions of charges resulting from the polarization of the dielectric.

Damping Coefficient (δ). If F is a function of time given by

$$F = A \exp(-\delta t) \sin(2\pi t/T)$$

then δ is the damping coefficient.

Elastance (S). Elastance is the reciprocal of capacitance.

Electric Charge, Quantity of Electricity (Q). Electric charge is a fundamentally assumed concept required by the existence of forces measurable experimentally. It has two forms known as positive and negative. The electric charge on (or in) a body or within a closed surface is the excess of one form of electricity over the other.

Electric Constant, Permittivity of Vacuum (Γ_e). The electric constant pertinent to any system of units is the scalar which in that system relates the electric flux density D in vacuum, to E, the electric field strength ($D = \Gamma_e E$). It also relates the mechanical force between two charges in vacuum to their magnitudes and separation. Thus, in the equation $F = \Gamma_r Q_1 Q_2 / 4\pi \Gamma_e r^2$, the force F between charges Q_1 and Q_2 separated by a distance r Γ_e is the electric constant, and Γ_r is a dimensionless factor which is unity in a rationalized system and 4π in an unrationalized system.

NOTE: In the cgs electrostatic system, Γ_e is assigned measure unity and the dimension "numeric." In the cgs electromagnetic system, the measure of Γ_e is that of $1/c^2$, and the dimension is $[L^{-2}T^2]$. In the International System, the measure of Γ_e is $10^7/4\pi c^2$, and the dimension is $[L^{-3}M^{-1}T^4I^2]$. Here, c is the speed of light expressed in the appropriate system of units (see Table 1-12).

*Electric Field Strength (**E**).* The electric field strength at a given point in an electric field is the vector limit of the quotient of the force that a small stationary charge at that point will experience, by virtue of its charge, as the charge approaches zero.

Electric Flux (Ψ). The electric flux through a surface is the surface integral of the normal component of the electric flux density over the surface.

*Electric Flux Density, Electric Displacement (**D**).* The electric flux density is a quantity related to the charge displaced within a dielectric by application of an electric field. Electric flux density at any point in an isotropic dielectric is a vector which has the same direction as the electric field strength, and a magnitude equal to the product of the electric field strength and the permittivity ϵ. In a nonisotropic medium, ϵ may be represented by a tensor and $\boldsymbol{D}$ is not necessarily parallel to $\boldsymbol{E}$.

*Electric Polarization (**P**).* The electric polarization is the vector quantity defined by the equation $\boldsymbol{P} = (\boldsymbol{D} - \Gamma_e \boldsymbol{E})/\Gamma_r$, where $\boldsymbol{D}$ is the electric flux density, Γ_e is the electric constant, $\boldsymbol{E}$ is the electric field strength, and Γ_r is a coefficient that is set equal to unity in a rationalized system and to 4π in an unrationalized system.

Electric Susceptibility (χ_e). Electric susceptibility is the quantity defined by $\chi_e = (\epsilon_r - 1)/\Gamma_r$, where ϵ_r is the relative permittivity and Γ_r is a coefficient that is set equal to unity in a rationalized system and to 4π in an unrationalized system.

Electrization (E_i). The electrization is the electric polarization divided by the electric constant of the system of units used.

Electrostatic Potential (V). The electrostatic potential at any point is the potential difference between that point and an agreed-on reference point, usually the point at infinity.

Electrostatic Potential Difference (V). The electrostatic potential difference between two points is the scalar-product line integral of the electric field strength along any path from one point to the other in an electric field, resulting from a static distribution of electric charge.

Impedance (Z). An impedance of a linear constant-parameter system is the ratio of the phasor equivalent of a steady-state sine-wave voltage or voltage-like quantity (driving force) to the phasor equivalent of a steady-state sine-wave current or current-like quantity (response). In electromagnetic radiation, electric field strength is considered the driving force and magnetic field strength the response. In mechanical systems, mechanical force is always considered as a driving force and velocity as a response. In a general sense, the dimension (and unit) of impedance in a given application may be whatever results from the ratio of the dimensions of the quantity chosen as the driving force to the dimensions of the quantity chosen as the response. However, in the types of systems cited above, any deviation from the usual convention should be noted.

Mutual Impedance. Mutual impedance between two loops (meshes) is the factor by which the phasor equivalent of the steady-state sine-wave current in one loop must be multiplied to give

the phasor equivalent of the steady-state sine-wave voltage in the other loop caused by the current in the first loop.

Self-impedance. Self-impedance of a loop (mesh) is the impedance of a passive loop with all other loops of the open-circuited network.

Transfer Impedance. A transfer impedance is the impedance obtained when the response is determined at a point other than that at which the driving force is applied.

NOTE: In the case of an electric circuit, the response may be determined in any branch except that which contains the driving force.

Logarithmic Decrement (Λ). If F is a function of time given by

$$F = A \exp(-\delta t) \sin(2\pi t/T)$$

then the logarithmic decrement $\Lambda = T\delta$.

Magnetic Constant, Permeability of Vacuum (Γ_m). The magnetic constant pertinent to any system of units is the scalar which in that system relates the mechanical force between two currents in vacuum to their magnitudes and geometric configurations. For example, the equation for the force F on a length l of two parallel straight conductors of infinite length and negligible circular cross section, carrying constant currents I_1 and I_2 and separated by a distance r in vacuum, is $F = \Gamma_m \Gamma_r I_{12} l/2\pi r$, where Γ_m is the magnetic constant and Γ_r is a coefficient set equal to unity in a rationalized system and to 4π in an unrationalized system.

NOTE: In the cgs electromagnetic system, Γ_m is assigned the magnitude unity and the dimension "numeric." In the cgs electrostatic system, the magnitude of Γ_m is that of $1/c^2$, and the dimension is $[L^{-2}T^2]$. In the International System, Γ_m is assigned the magnitude $4\pi \times 10^{-7}$ and has the dimension $[LMT^{-2}I^{-2}]$.

Magnetic Field Strength ($\boldsymbol{H}$). Magnetic field strength is that vector point function whose curl is the current density and which is proportional to magnetic flux density in regions free of magnetized matter.

Magnetic Flux (Φ). The magnetic flux through a surface is the surface integral of the normal component of the magnetic flux density over the surface.

Magnetic Flux Density, Magnetic Induction ($\boldsymbol{B}$). Magnetic flux density is that vector quantity which produces a torque on a plane current loop in accordance with the relation $\boldsymbol{T} = IA\boldsymbol{n} \times \boldsymbol{B}$, where $\boldsymbol{n}$ is the positive normal to the loop and A is its area. The concept of flux density is extended to a point inside a solid body by defining the flux density at such a point as that which would be measured in a thin disk-shaped cavity in the body centered at that point, the axis of the cavity being in the direction of the flux density.

Magnetic Moment ($\boldsymbol{m}$). The magnetic moment of a magnetized body is the volume integral of the magnetization. The magnetic moment of a loop carrying current I is $\boldsymbol{m} = (1/2)\int \boldsymbol{r} \times d\boldsymbol{r}$, where $\boldsymbol{r}$ is the radius vector from an arbitrary origin to a point on the loop, and where the path of integration is taken around the entire loop.

NOTE: The magnitude of the moment of a plane current loop is IA, where A is the area of the loop. The reference direction for the current in the loop indicates a clockwise rotation when the observer is looking through the loop in the direction of the positive normal.

Magnetic Polarization, Intrinsic Magnetic Flux Density ($\boldsymbol{J}$, $\boldsymbol{B}_i$). The magnetic polarization is the vector quantity defined by the equation $\boldsymbol{J} = (\boldsymbol{B} - \Gamma_m \boldsymbol{H})/\Gamma_r$, where $\boldsymbol{B}$ is the magnetic flux density, Γ_m is the magnetic constant, $\boldsymbol{H}$ is the magnetic field strength, and Γ_r is a coefficient that is set equal to unity in a rationalized system and to 4π in an unrationalized system.

Magnetic Susceptibility (χ_m). Magnetic susceptibility is the quantity defined by $\chi_m = (\mu_r - 1)/\Gamma_r$, where μ_r is the relative permeability and Γ_r is a coefficient that is set equal to unity in a rationalized system and to 4π in an unrationalized system.

Magnetic Vector Potential ($\boldsymbol{A}$). The magnetic vector potential is a vector point function characterized by the relation that its curl is equal to the magnetic flux density and its divergence vanishes.

Magnetization ($\boldsymbol{M}$, $\boldsymbol{H}_i$). The magnetization is the magnetic polarization divided by the magnetic constant of the system of units used.

Magnetomotive Force ($\boldsymbol{F}_m$). The magnetomotive force acting in any closed path in a magnetic field is the line integral of the magnetic field strength around the path.

Mutual Inductance (M). The mutual inductance between two loops (meshes) in a circuit is the quotient of the flux linkage produced in one loop divided by the current in another loop, which induces the flux linkage.

Permeability. Permeability is a general term used to express various relationships between magnetic flux density and magnetic field strength. These relationships are either (1) *absolute permeability* (μ), which in general is the quotient of a change in magnetic flux density divided by the corresponding change in magnetic field strength, or (2) *relative permeability* (μ_r), which is the ratio of the absolute permeability to the magnetic constant.

Permeance (P_m). Permeance is the reciprocal of reluctance.

Permittivity, Capacitivity (ϵ). The permittivity of a homogeneous, isotropic dielectric, in any system of units, is the product of its relative permittivity and the electric constant appropriate to that system of units.

Relative Permittivity, Relative Capacitivity, Dielectric Constant (ϵ_r). The relative permittivity of any homogeneous isotropic material is the ratio of the capacitance of a given configuration of electrodes with the material as a dielectric to the capacitance of the same electrode configuration with a vacuum as the dielectric constant. Experimentally, vacuum must be replaced by the material at all points where it makes a significant change in the capacitance.

Power (P). Power is the time rate of transferring or transforming energy. *Electric power* is the time rate of flow of electrical energy. The *instantaneous electric power* at a single terminal pair is equal to the product of the instantaneous voltage multiplied by the instantaneous current. If both voltage and current are periodic in time, the time average of the instantaneous power, taken over an integral number of periods, is the *active power,* usually called simply the *power* when there is no danger of confusion.

If the voltage and current are sinusoidal functions of time, the product of the rms value of the voltage and the rms value of the current is called the *apparent power;* the product of the rms value of the voltage and the rms value of the in-phase component of the current is the *active power;* and the product of the rms value of the voltage and the rms value of the quadrature component of the current is called the *reactive power*.

The SI unit of instantaneous power and active power is the watt. The germane unit for apparent power is the voltampere and for reactive power it is the var.

Power Factor (F_p). Power factor is the ratio of active power to apparent power.

Q. Q, sometimes called *quality factor,* is that measure of the quality of a component, network, system, or medium considered as an energy storage unit in the steady state with sinusoidal driving force which is given by

$$Q = \frac{2\pi \times (\text{maximum energy in storage})}{\text{energy dissipated per cycle of the driving force}}$$

NOTE: For single components such as inductors and capacitors, the Q at any frequency is the ratio of the equivalent series reactance to resistance, or of the equivalent shunt susceptance to conductance. For networks that contain several elements and for distributed parameter systems, the Q is generally evaluated at a frequency of resonance. The *nonloaded Q* of a system is the value of Q obtained when only the incidental dissipation of the system elements is present. The *loaded Q* of a system is the value Q obtained when the system is coupled to a device that dissipates energy. The "period" in the expression for Q is that of the driving force, not that of energy storage, which is usually half of that of the driving force.

Reactance (X). Reactance is the imaginary part of impedance.

Reluctance (R_m). Reluctance is the ratio of the magnetomotive force in a magnetic circuit to the magnetic flux through any cross section of the magnetic circuit.

Reluctivity (ν). Reluctivity is the reciprocal of permeability.

Resistance (R)

1. The resistance of an element, device, branch, network, or system is the factor by which the mean-square conduction current must be multiplied to give the corresponding power lost by dissipation as heat or as other permanent radiation or as electromagnetic energy from the circuit.
2. Resistance is the real part of impedance.

Resistivity (ρ). The resistivity of a material is a factor such that the conduction current density is equal to the electric field strength in the material divided by the resistivity.

Self-inductance (L)

1. Self-inductance is the quotient of the flux linkage of a circuit divided by the current in that same circuit which induces the flux linkage. If v = voltage induced, $v = d(Li)/dt$.
2. Self-inductance is the factor L in the $\frac{1}{2}Li^2$ if the latter gives the energy stored in the magnetic field as a result of the current i.

NOTE: Definitions 1 and 2 are not equivalent except when L is constant. In all other cases, the definition being used must be specified. The two definitions are restricted to relatively slow changes in i, that is, to low frequencies, but by analogy with the definitions, equivalent inductances often may be evolved in high-frequency applications such as resonators and waveguide equivalent circuits. Such "inductances," when used, must be specified. The two definitions are restricted to cases in which the branches are small in physical size when compared with a wavelength, whatever the frequency. Thus, in the case of a uniform 2-wire transmission line it may be necessary even at low frequencies to consider the parameters as "distributed" rather than to have one inductance for the entire line.

Susceptance (B). Susceptance is the imaginary part of admittance.

Transfer Function (H). A transfer function is that function of frequency which is the ratio of a phasor output to a phasor input in a linear system.

Transfer Ratio (H). A transfer ratio is a dimensionless transfer function.

Voltage, Electromotive Force (V). The voltage along a specified path in an electric field is the dot product line integral of the electric field strength along this path. As defined, here voltage is synonymous with potential difference only in an electrostatic field.

1.11 DEFINITIONS OF QUANTITIES OF RADIATION AND LIGHT

The following definitions are based on the principal meanings listed in the *IEEE Standard Dictionary* (ANSI/IEEE Std 100-1988), which should be consulted for extended meanings, compound terms, and related definitions. The symbols shown in parentheses are from Table 1-10.

Candlepower. Candlepower is luminous intensity expressed in candelas (term deprecated by IEEE).

Emissivity, Total Emissivity (ϵ). The total emissivity of an element of surface of a temperature radiator is the ratio of its radiant flux density (radiant exitance) to that of a blackbody at the same temperature.

Spectral Emissivity, $\epsilon(\lambda)$. The spectral emissivity of an element of surface of a temperature radiator at any wavelength is the ratio of its radiant flux density per unit wavelength interval (spectral radiant exitance) at that wavelength to that of a blackbody at the same temperature.

Light. For the purposes of illuminating engineering, light is visually evaluated radiant energy.

NOTE 1: Light is psychophysical, neither purely physical nor purely psychological. Light is not synonymous with radiant energy, however restricted, nor is it merely sensation. In a general nonspecialized sense, light is the aspect of radiant energy of which a human observer is aware through the stimulation of the retina of the eye.

NOTE 2: Radiant energy outside the visible portion of the spectrum must not be discussed using the quantities and units of light; it is nonsense to refer to "ultraviolet light" or to express infrared flux in lumens.

Luminance (Photometric Brightness) (L). Luminance in a direction, at a point on the surface of a source, or of a receiver, or on any other real or virtual surface is the quotient of the luminous flux (Φ) leaving, passing through, or arriving at a surface element surrounding the point, propagated in directions defined by an elementary cone containing the given direction, divided by the product of the solid angle of the cone ($d\omega$) and the area of the orthogonal projection of the surface element on a plane perpendicular to the given direction ($dA \cos \theta$). $L = d^2\Phi/[d\omega(da \cos \theta)] = dI/(dA \cos \theta)$. In the defining equation, θ is the angle between the direction of observation and the normal to the surface.

In common usage, the term *brightness* usually refers to the intensity of sensation which results from viewing surfaces or spaces from which light comes to the eye. This sensation is determined in part by the definitely measurable luminance defined above and in part by conditions of observation such as the state of adaptation of the eye. In much of the literature, the term *brightness,* used alone, refers to both luminance and sensation. The context usually indicates which meaning is intended.

Luminous Efficacy of Radiant Flux. The luminous efficacy of radiant flux is the quotient of the total luminous flux divided by the total radiant flux. It is expressed in lumens per watt.

Spectral Luminous Efficacy of Radiant Flux, K(λ). Spectral luminous efficacy of radiant flux is the quotient of the luminous flux at a given wavelength divided by the radiant flux at the wavelength. It is expressed in lumens per watt.

Spectral Luminous Efficiency of Radiant Flux. Spectral luminous efficiency of radiant flux is the ratio of the luminous efficacy for a given wavelength to the value at the wavelength of maximum luminous efficacy. It is a numeric.

NOTE: The term *spectral luminous efficiency* replaces the previously used terms *relative luminosity* and *relative luminosity factor.*

Luminous Flux (Φ). Luminous flux is the time rate of flow of light.

Luminous Flux Density at a Surface. Luminous flux density at a surface is luminous flux per unit area of the surface. In referring to flux incident on a surface, this is called *illumination (E)*. The preferred term for luminous flux *leaving* a surface is *luminous exitance (M)*, which has been called *luminous emittance.*

Luminous Intensity (I). The luminous intensity of a source of light in a given direction is the luminous flux proceeding from the source per unit solid angle in the direction considered ($I = d\Phi/d\omega$).

Quantity of Light (Q). Quantity of light (luminous energy) is the product of the luminous flux by the time it is maintained, that is, it is the time integral of luminous flux.

Radiance (L). Radiance in a direction, at a point on the surface, of a source, or of a receiver, or on any other real or virtual surface is the quotient of the radiant flux (P) leaving, passing through, or arriving at a surface element surrounding the point, and propagated in directions defined by an elementary cone containing the given direction, divided by the product of the solid angle of the cone ($d\omega$) and the area of the orthogonal projection of the surface element on a plane perpendicular to the given direction ($dA \cos \theta$). $L = d^2P/d\omega\,(dA \cos \theta) = dI/(dA \cos \theta)$. In the defining equation, θ is the angle between the normal to the element of the source and the direction of observation.

Radiant Density (w). Radiant density is radiant energy per unit volume.

Radiant Energy (W). Radiant energy is energy traveling in the form of electromagnetic waves.

Radiant Flux Density at a Surface. Radiant flux density at a surface is radiant flux per unit area of the surface. When referring to radiant flux incident on a surface, this is called *irradiance (E)*. The preferred term for radiant flux *leaving* a surface is *radiant exitance (M)*, which has been called *radiant emittance.*

Radiant Intensity (I). The radiant intensity of a source in a given direction is the radiant flux proceeding from the source per unit solid angle in the direction considered ($I = dP/d\omega$).

Radiant Power, Radiant Flux (P). Radiant flux is the time rate of flow of radiant energy.

1.12 LETTER SYMBOLS

Tables 1-10 and 1-11 list the United States Standard letter symbols for quantities and units (ANSI Std Y10.5, ANSI/IEEE Std 260). A *quantity symbol* is a single letter (e.g., *I* for electric current) specified as to general form of type and modified by one or more subscripts or superscripts when appropriate. A *unit symbol* is a letter or group of letters (e.g., cm for centimeter), or in a few cases, a special sign, that may be used in the place of the name of the unit.

Symbols for quantities are printed in *italic* type, while symbols for units are printed in roman type. Subscripts and superscripts that are letter symbols for quantities or for indices are printed in roman type as follows:

C_p	heat capacity at constant pressure p
a_{ij}, a_{45}	matrix elements
I_i, I_o	input current, output current

For indicating the vector character of a quantity, ***boldface italic*** type is used (e.g., ***F*** for force). Ordinary italic type is used to represent the magnitude of a vector quantity.

The product of two quantities is indicated by writing *ab*. The quotient may be indicated by writing

$$\frac{a}{b}, \qquad a/b, \qquad \text{or} \qquad ab^{-1}$$

If more than one solidus (/) is required in any algebraic term, parentheses must be inserted to remove any ambiguity. Thus, one may write $(a/b)/c$ or a/bc, but not $a/b/c$.

Unit symbols are written in lowercase letters, except for the first letter when the name of the unit is derived from a proper name, and except for a very few that are not formed from letters. When a compound unit is formed by multiplication of two or more other units, its symbol consists of the symbols for the separate units joined by a raised dot (e.g., N · m for newton = meter). The dot may be omitted in the case of familiar compounds such as watthour (Wh) if no confusion would result. Hyphens should not be used in symbols for compound units. Positive and negative exponents may be used with the symbols for units.

When a symbol representing a unit that has a prefix (see Sec. 1.5) carries an exponent, this indicates that the multiple (or submultiple) unit is raised to the power expressed by the exponent.

Examples:

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

$$1\ \text{ms}^{-1} = 1(\text{ms})^{-1} = 1(10^{-3}\ \text{s})^{-1} = 10^3\ \text{s}^{-1}$$

Phasor Quantities, represented by complex numbers or complex time-varying functions, are extensively used in certain branches of electrical engineering. The following notation and typography are standard:

	Notation	Remarks
Complex quantity	Z	$Z = \lvert Z\rvert \exp(j\phi)$ $Z = \text{Re}\ Z + j\ \text{Im}\ Z$
Real part	Re Z, Z'	
Imaginary part	Im Z, Z''	
Conjugate complex quantity	Z^*	$Z^* = \text{Re}\ Z - j\ \text{Im}\ Z$
Modulus of Z	$\lvert Z\rvert$	
Phase of Z, Argument of Z	arg Z	$\arg Z = \phi$

TABLE 1-10 Standard Symbols for Quantities

Quantity	Quantity symbol	Unit based on International System	Remarks
Space and time:			
Angle, plane	$\alpha,\beta,\gamma,\theta,\phi,\psi$	radian	Other Greek letters are permitted where no conflict results.
Angle, solid	$\Omega \cdots \omega$	steradian	
Length	l	meter	
Breadth, width	b	meter	
Height	h	meter	
Thickness	d, δ	meter	
Radius	r	meter	
Diameter	d	meter	
Length of path line segment	s	meter	
Wavelength	λ	meter	
Wave number	$\sigma \cdots \tilde{\nu}$	reciprocal meter	$\sigma = 1/\lambda$ The symbol $\tilde{\nu}$ is used in spectroscopy.
Circular wave number Angular wave number	k	radian per meter	$k = 2\pi/\lambda$
Area	$A \cdots S$	square meter	
Volume	V, υ	cubic meter	
Time	t	second	
Period	T	second	
Time constant	$\tau \cdots T$	second	
Frequency	$f \cdots \nu$	second	
Speed of rotation Rotational frequency	n	revolution per second	
Angular frequency	ω	radian per second	$\omega = 2\pi f$
Angular velocity	ω	radian per second	
Complex (angular) frequency Oscillation constant	$p \cdots s$	reciprocal second	$p = -\delta + j\omega$
Angular acceleration	α	radian per second squared	
Velocity	υ	meter per second	
Speed of propagation of electromagnetic waves	c	meter per second	In vacuum, c_0
Acceleration (linear)	a	meter per second squared	
Acceleration of free fall Gravitational acceleration	g	meter per second squared	
Damping coefficient	δ	neper per second	
Logarithmic decrement	Λ	(numeric)	
Attenuation coefficient	α	neper per meter	
Phase coefficient	β	radian per meter	
Propagation coefficient	γ	reciprocal meter	$\gamma = \alpha + j\beta$
Mechanics:			
Mass	m	kilogram	
(Mass) density	ρ	kilogram per cubic meter	Mass divided by volume
Momentum	p	kilogram meter per second	
Moment of inertia	I, J	kilogram meter squared	

TABLE 1-10 Standard Symbols for Quantities (*Continued*)

Quantity	Quantity symbol	Unit based on International System	Remarks
Force	F	newton	
Weight	W	newton	Varies with acceleration of free fall
Weight density	γ	newton per cubic meter	Weight divided by volume
Moment of force	M	newton meter	
Torque	$T \cdot \cdot \cdot M$	newton meter	
Pressure	p	newton per square meter	The SI name *pascal* has been adopted for this unit.
Normal stress	σ	newton per square meter	
Shear stress	τ	newton per square meter	
Stress tensor	σ	newton per square meter	
Linear strain	ε	(numeric)	
Shear strain	γ	(numeric)	
Strain tensor	ε	(numeric)	
Volume strain	θ	(numeric)	
Poisson's ratio	μ, ν	(numeric)	Lateral contraction divided by elongation
Young's modulus Modulus of elasticity	E	newton per square meter	$E = \sigma/\varepsilon$
Shear modulus Modulus of rigidity	G	newton per square meter	$G = \tau/\gamma$
Bulk modulus	K	newton per square meter	$K = -p/\theta$
Work	W	joule	
Energy	E, W	joule	U is recommended in thermodynamics for internal energy and for blackbody radiation.
Energy (volume) density	w	joule per cubic meter	
Power	P	watt	
Efficiency	η	(numeric)	
Heat:			
Thermodynamic temperature	$T \cdot \cdot \cdot \Theta$	kelvin	
Temperature Customary temperature	$t \cdot \cdot \cdot \theta$	degree Celsius	The word *centigrade* has been abandoned as the name of a temperature scale.
Heat	Q	joule	
Internal energy	U	joule	
Heat flow rate	$\Phi \cdot \cdot \cdot q$	watt	Heat crossing a surface divided by time
Temperature coefficient	α	reciprocal kelvin	
Thermal diffusivity	α	square meter per second	
Thermal conductivity	$\lambda \cdot \cdot \cdot k$	watt per meter kelvin	
Thermal conductance	G_θ	watt per kelvin	
Thermal resistivity	ρ_θ	meter kelvin per watt	
Thermal resistance	R_θ	kelvin per watt	
Thermal capacitance Heat capacity	C_θ	joule per kelvin	
Thermal impedance	Z_θ	kelvin per watt	
Specific heat capacity	c	joule per kelvin kilogram	Heat capacity divided by mass
Entropy	S	joule per kelvin	
Specific entropy	s	joule per kelvin kilogram	Entropy divided by mass
Enthalpy	H	joule	
Radiation and light:			
Radiant intensity	$I \cdot \cdot \cdot I_e$	watt per steradian	
Radiant power Radiant flux	$P, \Phi \cdot \cdot \cdot \Phi_e$	watt	

(*Continued*)

TABLE 1-10 Standard Symbols for Quantities (*Continued*)

Quantity	Quantity symbol	Unit based on International System	Remarks
Radiant energy	$W, Q \cdots Q_e$	joule	The symbol U is used for the special case of blackbody radiant energy
Radiance	$L \cdots L_e$	watt per steradian square meter	
Radiant exitance	$M \cdots M_e$	watt per square meter	
Irradiance	$E \cdots E_e$	watt per square meter	
Luminous intensity	$I \cdots I_v$	candela	
Luminous flux	$\Phi \cdots \Phi_v$	lumen	
Quantity of light	$Q \cdots Q_v$	lumen second	
Luminance	$L \cdots L_v$	candela per square meter	
Luminous exitance	$M \cdots M_v$	lumen per square meter	
Illuminance Illumination	$E \cdots E_v$	lux	
Luminous efficacy†	$K(\lambda)$	lumen per watt	
Total luminous efficacy	K, K_t	lumen per watt	
Refractive index Index of refraction	n	(numeric)	
Emissivity†	$\epsilon(\lambda)$	(numeric)	
Total emissivity	ϵ, ϵ_t	(numeric)	
Absorptance†	$\alpha(\lambda)$	(numeric)	
Transmittance†	$\tau(\lambda)$	(numeric)	
Reflectance†	$\rho(\lambda)$	(numeric)	
Fields and circuits:			
Electric charge Quantity of electricity	Q	coulomb	
Linear density of charge	λ	coulomb per meter	
Surface density of charge	σ	coulomb per square meter	
Volume density of charge	ρ	coulomb per cubic meter	
Electric field strength	$E \cdots K$	volt per meter	
Electrostatic potential Potential difference	$V \cdots \phi$	volt	
Retarded scalar potential	V_r	volt	
Voltage Electromotive force	$V, E \cdots U$	volt	
Electric flux	Ψ	coulomb	
Electric flux density (Electric) displacement	D	coulomb per square meter	
Capacitivity Permittivity Absolute permittivity	ϵ	farad per meter	Of vacuum, ε_v
Relative capacitivity Relative permittivity Dielectric constant	ϵ_r, κ	(numeric)	
Complex relative capacitivity	ϵ_r^*, κ^*	(numeric)	$\epsilon_r^* = \epsilon'_r - j\epsilon''_r$
Complex relative permittivity Complex dielectric constant			ϵ'_r is positive for lossy materials. The complex absolute permittivity ϵ^* is defined in analogous fashion.

TABLE 1-10 Standard Symbols for Quantities (*Continued*)

Quantity	Quantity symbol	Unit based on International System	Remarks	
Electric susceptibility	$\chi_e \cdots \epsilon_i$	(numeric)	$\chi_e = \epsilon_r - 1$	MKSA
Electrization	$E_i \cdots K_i$	volt per meter	$E_i = (D/\Gamma_e) - E$	MKSA
Electric polarization	P	coulomb per square meter	$P = D - \Gamma_e E$	MKSA
Electric dipole moment	p	coulomb meter		
(Electric) current	I	ampere		
Current density	$J \cdots S$	ampere per square meter		
Linear current density	$A \cdots \alpha$	ampere per meter	Current divided by the breadth of the conducting sheet	
Magnetic field strength	H	ampere per meter		
Magnetic (scalar) potential Magnetic potential difference	U, U_m	ampere		
Magnetomotive force	$F, F_m \cdots \mathcal{F}$	ampere		
Magnetic flux	Φ	weber		
Magnetic flux density Magnetic induction	B	tesla		
Magnetic flux linkage	Λ	weber		
(Magnetic) vector potential	A	weber per meter		
Retarded (magnetic) vector potential	A_r	weber per meter		
Permeability Absolute permeability	μ	henry per meter	Of vacuum, μ_v	
Relative permeability	μ_r	(numeric)		
Initial (relative) permeability	μ_o	(numeric)		
Complex relative permeability	μ_r^*	(numeric)	$\mu_r^* = \mu_r' - j\mu_r''$ μ_r'' is positive for lossy materials. The complex absolute permeability μ^* is defined in analogous fashion.	
Magnetic susceptibility	$\chi_m \cdots \mu_i$	(numeric)	$\chi_m = \mu_r - 1$	MKSA
Reluctivity	ν	meter per henry	$\nu = 1/\mu$	
Magnetization	H_i, M	ampere per meter	$H_i = (B/\Gamma_m) - H$	MKSA
Magnetic polarization Intrinsic magnetic flux density	J, B_i	tesla	$J = B - \Gamma_m H$	MKSA
Magnetic (area) moment	m	ampere meter squared	The vector product $\boldsymbol{m} \times \boldsymbol{B}$ is equal to the torque.	
Capacitance	C	farad		
Elastance	S	reciprocal farad	$S = 1/C$	
(Self-) inductance	L	henry		
Reciprocal inductance	Γ	reciprocal henry		
Mutual inductance	L_{ij}, M_{ij}	henry	If only a single mutual inductance is involved, M may be used without subscripts.	
Coupling coefficient	$k \cdots \kappa$	(numeric)	$k = L_{ij}(L_i L_j)^{-1/2}$	
Leakage coefficient	σ	(numeric)	$\sigma = 1 - k^2$	
Number of turns (in a winding)	N, n	(numeric)		
Number of phases	m	(numeric)		
Turns ratio	$n \cdots n_*$	(numeric)		

(*Continued*)

TABLE 1-10 Standard Symbols for Quantities (*Continued*)

Quantity	Quantity symbol	Unit based on International System	Remarks
Transformer ratio	a	(numeric)	Square root of the ratio of secondary to primary self-inductance. Where the coefficient of coupling is high, $a \approx n_*$.
Resistance	R	ohm	
Resistivity Volume resistivity	ρ	ohm meter	
Conductance	G	siemens	$G = \text{Re } Y$
Conductivity	γ, σ	siemens per meter	$\gamma = 1/\rho$ The symbol σ is used in field theory, as γ is there used for the propagation coefficient.
Reluctance	$R, R_m \cdots \mathcal{R}$	reciprocal henry	Magnetic potential difference divided by magnetic flux
Permeance	$P, P_m \cdots \mathcal{P}$	henry	$P_m = 1/R_m$
Impedance	Z	ohm	
Reactance	X	ohm	
Capacitive reactance	X_C	ohm	For a pure capacitance, $X_C = -1/\omega C$
Inductive reactance	X_L	ohm	For a pure capacitance, $X_L = \omega L$
Quality factor	Q	(numeric)	See Q in Sec. 1.10.
Admittance	Y	siemens	$Y = 1/Z = G + jB$
Susceptance	B	siemens	$B = \text{Im } Y$
Loss angle	δ	radian	$\delta = (R/\lvert X \rvert)$
Active power	P	watt	
Reactive power	$Q \cdots P_q$	var	
Apparent power	$S \cdots P_s$	voltampere	
Power factor	$\cos \phi \cdots F_p$	(numeric)	
Reactive factor	$\sin \phi \cdots F_q$	(numeric)	
Input power	P_i	watt	
Output power	P_o	watt	
Poynting vector	S	watt per square meter	
Characteristic impedance Surge impedance	Z_o	ohm	
Intrinsic impedance of a medium	η	ohm	
Voltage standing-wave ratio	S	(numeric)	
Resonance frequency	f_r	hertz	
Critical frequency Cutoff frequency	f_c	hertz	
Resonance angular frequency	ω_r	radian per second	
Critical angular frequency Cutoff angular frequency	ω_c	radian per second	
Resonance wavelength	λ_r	meter	
Critical wavelength Cutoff wavelength	λ_c	meter	
Wavelength in a guide	λ_g	meter	
Hysteresis coefficient	k_h	(numeric)	
Eddy-current coefficient	k_e	(numeric)	
Phase angle Phase difference	ϕ, θ	radian	

[†](λ) is not part of the basic symbol but indicates that the quantity is a function of wavelength.

TABLE 1-11 Standard Symbols for Units

Unit	Symbol	Notes
ampere	A	SI unit of electric current
ampere (turn)	A	SI unit of magnetomotive force
ampere-hour	Ah	Also A · h
ampere per meter	A/m	SI unit of magnetic field strength
angstrom	Å	1 Å = 10^{-10} m. Deprecated.
atmosphere, standard	atm	1 atm = 101 325 Pa. Deprecated.
atmosphere, technical	at	1 at = 1 kgf/cm^2. Deprecated.
atomic mass unit (unified)	u	The (unified) atomic mass unit is defined as one-twelfth of the mass of an atom of the ^{12}C nuclide. Use of the old atomic mass (amu), defined by reference to oxygen, is deprecated.
atto	a	SI prefix for 10^{-18}
attoampere	aA	
bar	bar	1 bar = 100 kPa. Use of the bar is strongly discouraged, except for limited use in meteorology.
barn	b	1 b = 10^{-28} m^2
barrel	bb1	1 bb1 = 42 gal_{US} = 158.99 L
barrel per day	bb1/d	This is the standard barrel used for petroleum, etc. A different standard barrel is used for fruits, vegetables, and dry commodities.
baud	Bd	In telecommunications, a unit of signaling speed equal to one element per second. The signaling speed in bauds is equal to the reciprocal of the signal element length in seconds.
bel	B	
becquerel	Bq	SI unit of activity of a radionuclide
billion electronvolts	GeV	The name *gigaelectronvolt* is preferred for this unit.
bit	b	In information theory, the bit is a unit of information content equal to the information content of a message, the *a priori* probability of which is one-half. In computer science, the bit is a unit of storage capacity. The capacity, in bits, of a storage device is the logarithm to the base two of the number of possible states of the device.
bit per second	b/s	
British thermal unit	Btu	
calorie (International Table calorie)	cal_{IT}	1 cal_{IT} = 4.1868 J. Deprecated.
calorie (thermochemical calorie)	cal	1 cal = 4.1840 J. Deprecated.
candela	cd	SI unit of luminous intensity
candela per square inch	cd/in^2	Use of the SI unit, cd/m^2, is preferred.
candela per square meter	cd/m^2	SI unit of luminance. The name *nit* is sometimes used for this unit.
candle	cd	The unit of luminous intensity has been given the name *candela;* use of the name *candle* for this unit is deprecated.
centi	c	SI prefix for 10^{-2}
centimeter	cm	
centipoise	cP	1 cP = mPa · s. The name centipoise is deprecated.
centistokes	cSt	1 cSt = 1 mm^2/s. The name centistokes is deprecated.
circular mil	cmil	1 cmil = $(\pi/4) \cdot 10^{-6}$ in^2
coulomb	C	SI unit of electric charge
cubic centimeter	cm^3	
cubic foot	ft^3	
cubic foot per minute	ft^3/min	
cubic foot per second	ft^3/s	
cubic inch	in^3	
cubic meter	m^3	
cubic meter per second	m^3/s	
cubic yard	yd^3	

(*Continued*)

TABLE 1-11 Standard Symbols for Units (*Continued*)

Unit	Symbol	Notes
curie	Ci	A unit of activity of radionuclide. Use of the SI unit, the becquerel, is preferred, 1 Ci = 3.7×10^{10} Bq.
cycle	c	
cycle per second	Hz, c/s	See hertz. The name *hertz* is internationally accepted for this unit; the symbol Hz is preferred to c/s.
darcy	D	1 D = 1 cP (cm/s) (cm/atm) = 0.986 923 μm^2. A unit of permeability of a porous medium. By traditional definition, a permeability of one darcy will permit a flow of 1 cm^3/s of fluid of 1 cP viscosity through an area of 1 cm^2 under a pressure gradient of 1 atm/cm. For nonprecision work, 1 D may be taken equal to 1 μm^2 and 1 mD equal to 0.001 μm^2. Deprecated.
day	d	
deci	d	SI prefix for 10^{-1}
decibel	dB	
degree (plane angle)	· · · °	
degree (temperature):		
degree Celsius	°C	SI unit of Celsius temperature. The degree Celsius is a special name for the kelvin, for use in expressing Celsius temperatures or temperature intervals.
degree Fahrenheit	°F	Note that the symbols for °C, °F, and °R comprise two elements, written with no space between the ° and the letter that follows. The two elements that make the complete symbol are not to be separated.
degree Kelvin		See kelvin
degree Rankine	°R	
deka	da	SI prefix for 10
dyne	dyn	Deprecated.
electronvolt	eV	
erg	erg	Deprecated.
exa	E	SI prefix for 10^{18}
farad	F	SI unit of capacitance
femto	f	SI prefix for 10^{-15}
femtometer	fm	
foot	ft	
conventional foot of water	ftH_2O	1 ftH_2O = 2989.1 Pa (ISO)
foot per minute	ft/min	
foot per second	ft/s	
foot per second squared	ft/s^2	
foot pound-force	ft · lbf	
footcandle	fc	1 fc = 1 lm/ft^2. The name *lumen per square foot* is also used for this unit. Use of the SI unit of illuminance, the lux (lumen per square meter), is preferred.
footlambert	fL	1 fL = $(1/\pi)$ cd/ft^2. A unit of luminance. One lumen per square foot leaves a surface whose luminance is one footlambert in all directions within a hemisphere. Use of the SI unit, the candela per square meter, is preferred.
gal	Gal	1 Gal = 1 cm/s^2. Deprecated.
gallon	gal	1 gal_{UK} = 4.5461 L 1 gal_{US} = 231 in^3 = 3.7854 L
gauss	G	The gauss is the electromagnetic CGS unit of magnetic flux density. Deprecated.
giga	G	SI prefix for 10^9
gigaelectronvolt	GeV	
gigahertz	GHz	

TABLE 1-11 Standard Symbols for Units (*Continued*)

Unit	Symbol	Notes
gilbert	Gb	The gilbert is the electromagnetic CGS unit of magnetomotive force. Deprecated.
grain	gr	
gram	g	
gram per cubic centimeter	g/cm^3	
gray	Gy	SI unit of absorbed dose in the field of radiation dosimetry
hecto	h	SI prefix for 10^2
henry	H	SI unit of inductance
hertz	Hz	SI unit of frequency
horsepower	hp	The horsepower is an anachronism in science and technology. Use of the SI unit of power, the watt, is preferred.
hour	h	
inch	in	
conventional inch of mercury	inHg	1 inHg = 3386.4 Pa (ISO)
conventional inch of water	inH_2O	1 inH_2O = 249.09 Pa (ISO)
inch per second	in/s	
joule	J	SI unit of energy, work, quantity of heat
joule per kelvin	J/K	SI unit of heat capacity and entropy
kelvin	K	In 1967, the CGPM gave the name *kelvin* to the SI unit of temperature which had formerly been called *degree kelvin* and assigned it the symbol K (without the symbol °).
kilo	k	SI prefix for 10^3
kilogauss	kG	Deprecated.
kilogram	kg	SI unit of mass
kilogram-force	kgf	Deprecated. In some countries, the name kilopond (kp) has been used for this unit.
kilohertz	kHz	
kilohm	kΩ	
kilometer	km	
kilometer per hour	km/h	
kilopound-force	klbf	Kilopound-force should not be misinterpreted as kilopond (see kilogram-force).
kilovar	kvar	
kilovolt	kV	
kilovoltampere	kVA	
kilowatt	kW	
kilowatthour	kWh	Also kW · h
knot	kn	1kn = 1 nmi/h
lambert	L	1 L = $(1/\pi)$ cd/cm^2. A GGS unit of luminance. One lumen per square centimeter leaves a surface whose luminance is one lambert in all directions within a hemisphere. Deprecated.
liter	L	1 L = 10^{-3} m^3. The letter symbol l has been adopted for *liter* by the GGPM, and it is recommended in a number of international standards. In 1978, the CIPM accepted L as an alternative symbol. Because of frequent confusion with the numeral 1 the letter symbol l is no longer recommended for U.S. use. The script letter ℓ, which had been proposed, is not recommended as a symbol for liter.
liter per second	L/s	
lumen	lm	SI unit of luminous flux
lumen per square foot	lm/ft^2	A unit of illuminance and also a unit of luminous exitance. Use of the SI unit, lumen per square meter, is preferred.
lumen per square meter	lm/m^2	SI unit of luminous exitance
lumen per watt	lm/W	SI unit of luminous efficacy

(*Continued*)

TABLE 1-11 Standard Symbols for Units (*Continued*)

Unit	Symbol	Notes
lumen second	lm · s	SI unit of quantity of light
lux	lx	1 lx = 1 lm/m^2. SI unit of illuminance
maxwell	Mx	The maxwell is the electromagnetic CGS unit of magnetic flux. Deprecated.
mega	M	SI prefix for 10^6
megaelectronvolt	MeV	
megahertz	MHz	
megohm	MΩ	
meter	m	SI unit of length
metric ton	t	1 t = 1000 kg. The name *tonne* is used in some countries for this unit, but use of this name in the U.S. is deprecated.
mho	mho	Formerly used as the name of the siemens (S).
micro	μ	SI prefix for 10^{-6}
microampere	μA	
microfarad	μF	
microgram	μg	
microhenry	μH	
microinch	μin	
microliter	μL	See note for *liter*.
micrometer	μm	
micron	μm	Deprecated. Use micrometer.
microsecond	μs	
microwatt	μW	
mil	mil	1 mil = 0.001 in
mile (statute)	mi	1 mi = 5280 ft
miles per hour	mi/h	Although use of mph as an abbreviation is common, it should not be used as a symbol.
milli	m	SI prefix for 10^{-3}
milliampere	mA	
millibar	mbar	Use of the bar is strongly discouraged, except for limited use in meteorology.
milligram	mg	
millihenry	mH	
milliliter	mL	See note for *liter*.
millimeter	mm	
conventional millimeter of mercury	mmHg	1 mmHg = 133.322 Pa. Deprecated.
millimicron	nm	Use of the name *millimicron* for the nanometer is deprecated.
millipascal second	mPa · s	SI unit-multiple of dynamic viscosity
millisecond	ms	
millivolt	mV	
milliwatt	mW	
minute (plane angle)	· · · ′	
minute (time)	min	Time may also be designated by means of superscripts as in the following example: $9^h46^m30^s$.
mole	mol	SI unit of amount of substance
month	mo	
nano	n	SI prefix for 10^{-9}
nanoampere	nA	
nanofarad	nF	
nanometer	nm	
nanosecond	ns	
nautical mile	nmi	1 nmi = 1852 m

TABLE 1-11 Standard Symbols for Units (*Continued*)

Unit	Symbol	Notes
neper	Np	
newton	N	SI unit of force
newton meter	N · m	
newton per square meter	N/m^2	SI unit of pressure or stress, see pascal.
nit	nt	1 nt = 1 cd/m^2 The name *nit* is sometimes given to the SI unit of luminance, the candela per square meter.
oersted	Oe	The oersted is the electromagnetic CGS unit of magnetic field strength. Deprecated.
ohm	Ω	SI unit of resistance
ounce (avoirdupois)	oz	
pascal	Pa	1 Pa = 1 N/m^2 SI unit of pressure or stress
pascal second	Pa · s	SI unit of dynamic viscosity
peta	P	SI prefix for 10^{15}
phot	ph	1 ph = lm/cm^2 CGS unit of illuminance. Deprecated.
pico	p	SI prefix for 10^{-12}
picofarad	pF	
picowatt	pW	
pint	pt	1 pt (U.K.) = 0.568 26 L 1 pt (U.S. dry) = 0.550 61 L 1 pt (U.S. liquid) = 0.473 18 L
poise	P	Deprecated.
pound	lb	
pound per cubic foot	lb/ft^3	
pound-force	lbf	
pound-force foot	lbf · ft	
pound-force per square foot	lbf/ft^2	
pound-force per square inch	lbf/in^2	Although use of the abbreviation psi is common, it should not be used as a symbol.
poundal	pdl	
quart	qt	1 qt (U.K.) = 1.136 5 L 1 qt (U.S. dry) = 1.101 2 L 1 qt (U.S. liquid) = 0.946 35 L
rad	rd	A unit of absorbed dose in the field of radiation dosimetry. Use of the SI unit, the gray, is preferred. 1 rd = 0.01 Gy.
radian	rad	SI unit of plane angle
rem	rem	A unit of dose equivalent in the field of radiation dosimetry. Use of the SI unit, the sievert, is preferred. 1 rem = 0.01 Sv.
revolution per minute	r/min	Although use of rpm as an abbreviation is common, it should not be used as a symbol.
revolution per second	r/s	
roentgen	R	A unit of exposure in the field of radiation dosimetry
second (plane angle)	· · · ″	
second (time)	s	SI unit of time
siemens	S	1 S = 1 Ω^{-1} SI unit of conductance. The name mho has been used for this unit in the U.S.
sievert	Sv	SI unit of dose equivalent in the field of radiation dosimetry. Name adopted by the CIPM in 1978.
slug	slug	1 slug = 14.5939 kg
square foot	ft^2	
square inch	in^2	

(*Continued*)

TABLE 1-11 Standard Symbols for Units (*Continued*)

Unit	Symbol	Notes
square meter	m^2	
square meter per second	m^2/s	SI unit of kinematic viscosity
square millimeter per second	mm^2/s	SI unit-multiple of kinematic viscosity
square yard	yd^2	
steradian	sr	SI unit of solid angle
stilb	sb	1 sb = 1 cd/cm^2 A CGS unit of luminance. Deprecated.
stokes	St	Deprecated.
tera	T	SI prefix for 10^{12}
tesla	T	1 T = 1 N/(A · m) = 1 Wb/m^2. SI unit of magnetic flux density (magnetic induction).
therm	thm	1 thm = 100 000 Btu
ton (short)	ton	1 ton = 2000 lb
ton, metic	t	1 t = 1000 kg. The name *tonne* is used in some countries for this unit, but use of this name in the U.S. is deprecated.
(unified) atomic mass unit	u	The (unified) atomic mass unit is defined as one-twelfth of the mass of an atom of the ^{12}C nuclide. Use of the old atomic mass unit (amu), defined by reference to oxygen, is deprecated.
var	var	IEC name and symbol for the SI unit of reactive power
volt	V	SI unit of voltage
volt per meter	V/m	SI unit of electric field strength
voltampere	VA	IEC name and symbol for the SI unit of apparent power
watt	W	SI unit of power
watt per meter kelvin	W/(m · K)	SI unit of thermal conductivity
watt per steradian	W/sr	SI unit of radiant intensity
watt per steradian square meter	W/(sr · m^2)	SI unit of radiance
watthour	Wh	
weber	Wb	Wb = V · s SI unit of magnetic flux
yard	yd	
year	a	In the English language, generally yr.

1.13 GRAPHIC SYMBOLS

An extensive list of standard graphic symbols for electrical engineering has been compiled in IEEE Standard 315 (ANSI Y32.2). Since this standard comprises 110 pages, including 78 pages of diagrams, it is impractical to reproduce it here. Those concerned with the preparation of circuit diagrams and graphic layouts should conform to these standard symbols to avoid confusion with earlier, nonstandard forms. See also Sec. 28.

1.14 PHYSICAL CONSTANTS

Table 1-12 lists the values of the fundamental physical constants, compiled by Peter J. Mohr and Barry N. Taylor of the Task Group on Fundamental Constants of the Committee on Data for Science and Technology (CODATA), sponsored by the International Council of Scientific Unions. Further details on the methods used to adjust these values to form a consistent set are contained in Ref. 10. Table 1-13 lists the values of some energy equivalents.

TABLE 1-12 Fundamental Physical Universal Constants

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
		UNIVERSAL		
speed of light in vacuum	c, c_0	299 792 458	m s^{-1}	(exact)
magnetic constant	μ_0	$4\pi \times 10^{-7}$	N A^{-2}	
		$= 12.566\ 370\ 614\ \ldots \times 10^{-7}$	N A^{-2}	(exact)
electric constant $1/\mu_0 c^2$	ϵ_0	$8.854\ 187\ 817\ \ldots \times 10^{-12}$	F m^{-1}	(exact)
characteristic impedance of vacuum $\sqrt{\mu_0/\epsilon_0} = \mu_0 c$	Z_0	376.730 313 461 …	Ω	(exact)
Newtonian constant of gravitation	G	$6.6742(10) \times 10^{-11}$	m^3 kg^{-1} s^{-2}	1.5×10^{-4}
	$G/\hbar c$	$6.7087(10) \times 10^{-39}$	$(GeV/c^2)^{-2}$	1.5×10^{-4}
Planck constant	h	$6.626\ 0693(11) \times 10^{-34}$	J s	1.7×10^{-7}
in eV s		$4.135\ 667\ 43(35) \times 10^{-15}$	eV s	8.5×10^{-8}
$h/2\pi$	$\hbar$	$1.054\ 571\ 68(18) \times 10^{-34}$	J s	1.7×10^{-7}
in eV s		$6.582\ 119\ 15(56) \times 10^{-16}$	eV s	8.5×10^{-8}
$\hbar c$ in MeV fm		197.326 968(17)	Me V fm	8.5×10^{-8}
Planck mass $(\hbar c/G)^{1/2}$	m_P	$2.176\ 45(16) \times 10^{-8}$	kg	7.5×10^{-5}
Planck temperature $(\hbar c^5/G)^{1/2}/k$	T_P	$1.416\ 79(11) \times 10^{32}$	K	7.5×10^{-5}
Planck length $\hbar/m_P c = (\hbar G/c^3)^{1/2}$	l_P	$1.616\ 24(12) \times 10^{-35}$	m	7.5×10^{-5}
Planck time $l_P/c = (\hbar G/c^5)^{1/2}$	t_P	$5.391\ 21(40) \times 10^{-44}$	s	7.5×10^{-5}
		ELECTROMAGNETIC		
elementary charge	e	$1.602\ 176\ 53(14) \times 10^{-19}$	C	8.5×10^{-8}
	e/h	$2.417\ 989\ 40(21) \times 10^{14}$	A J^{-1}	8.5×10^{-8}
magnetic flux quantum h/2e	Φ_0	$2.067\ 833\ 72(18) \times 10^{-15}$	Wb	8.5×10^{-8}
conductance quantum $2e^2/h$	G_0	$7.748\ 091\ 733(26) \times 10^{-5}$	S	3.3×10^{-9}
inverse of conductance quantum	${G_0}^{-1}$	12 906.403 725(43)	Ω	3.3×10^{-9}
Josephson constant $2e/h$	K_J	$483\ 597.879(41) \times 10^9$	Hz V^{-1}	8.5×10^{-8}
von Klitzing constant $h/e^2 = \mu_0 c/2\alpha$	R_K	25 812.807 449(86)	Ω	3.3×10^{-9}
Bohr magneton $e\hbar/2m_e$	μ_B	$927.400\ 949(80) \times 10^{-26}$	J T^{-1}	8.6×10^{-8}
in eV T^{-1}		$5.788\ 381\ 804(39) \times 10^{-5}$	eV T^{-1}	6.7×10^{-9}
	μ_B/h	$13.996\ 2458(12) \times 10^9$	Hz T^{-1}	8.6×10^{-8}
	μ_B/hc	46.686 4507(40)	m^{-1} T^{-1}	8.6×10^{-8}
	μ_B/k	0.671 7131(12)	K T^{-1}	1.8×10^{-6}
nuclear magneton $e\hbar/2m_P$	μ_N	$5.050\ 783\ 43(43) \times 10^{-27}$	J T^{-1}	8.6×10^{-8}
in eV T^{-1}		$3.152\ 451\ 259(21) \times 10^{-8}$	eV T^{-1}	6.7×10^{-9}
	μ_N/h	7.622 593 71(65)	MHz T^{-1}	8.6×10^{-8}
	μ_N/hc	$2.542\ 623\ 58(22) \times 10^{-2}$	m^{-1} T^{-1}	8.6×10^{-8}
	μ_N/k	$3.658\ 2637(64) \times 10^{-4}$	K T^{-1}	1.8×10^{-6}
		ATOMIC AND NUCLEAR		
		General		
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\ 352\ 568(24) \times 10^{-3}$		3.3×10^{-9}
inverse fine-structure constant	α^{-1}	137.035 999 11(46)		3.3×10^{-9}
Rydberg constant $\alpha^2 m_e c/2h$	$R\infty$	10 973 731.568 525(73)	m^{-1}	6.6×10^{-12}
	$R\infty c$	$3.289\ 841\ 960\ 360(22) \times 10^{15}$	Hz	6.6×10^{-12}
	$R\infty hc$	$2.179\ 872\ 09(37) \times 10^{-18}$	J	1.7×10^{-7}
	$R\infty hc$ in eV	13.605 6923(12)	eV	8.5×10^{-8}
Bohr radius $\alpha/4\pi R\infty = 4\pi\epsilon_0\hbar^2/m_e e^2$	a_0	$0.529\ 177\ 2108(18) \times 10^{-10}$	m	3.3×10^{-9}
Hartree energy $e^2/4\pi\epsilon_0 a_0 = 2R\infty hc$ $= \alpha^2 m_e c^2$	E_h	$4.359\ 744\ 17(75) \times 10^{-18}$	J	1.7×10^{-7}
in eV		27.211 3845(23)	eV	8.5×10^{-8}

(*Continued*)

TABLE 1-12 Fundamental Physical Universal Constants (*Continued*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
quantum of circulation	$h/2m_e$	$3.636\ 947\ 550(24) \times 10^{-4}$	$m^2\ s^{-1}$	6.7×10^{-9}
	h/m_e	$7.273\ 895\ 101(48) \times 10^{-4}$	$m^2\ s^{-1}$	6.7×10^{-9}
		Electroweak		
Fermi coupling constant[a]	$G_F/(\hbar c)^3$	$1.166\ 39(1) \times 10^{-5}$	GeV^{-2}	8.6×10^{-6}
weak mixing angle[b] θ_W (on-shell scheme)				
$\sin^2\theta_W = s^2_W \equiv 1 - (m_W/m_Z)^2$	$\sin^2\theta_W$	0.222 15(76)		3.4×10^{-3}
		Electron, e^-		
electron mass	m_e	$9.109\ 3826(16) \times 10^{-31}$	kg	1.7×10^{-7}
in u, $m_e = A_r(e)$ u (electron relative atomic mass times u)		$5.485\ 799\ 0945(24) \times 10^{-4}$	u	4.4×10^{-10}
energy equivalent	$m_e c^2$	$8.187\ 1047(14) \times 10^{-14}$	J	1.7×10^{-7}
in MeV		0.510 998 918(44)	MeV	8.6×10^{-8}
electron-muon mass ratio	m_e/m_μ	$4.836\ 331\ 67(13) \times 10^{-3}$		2.6×10^{-8}
electron-tau mass ratio	m_e/m_τ	$2.875\ 64(47) \times 10^{-4}$		1.6×10^{-4}
electron-proton mass ratio	m_e/m_p	$5.446\ 170\ 2173(25) \times 10^{-4}$		4.6×10^{-10}
electron-neutron mass ratio	m_e/m_n	$5.438\ 673\ 4481(38) \times 10^{-4}$		7.0×10^{-10}
electron-deuteron mass ratio	m_e/m_d	$2.724\ 437\ 1095(13) \times 10^{-4}$		4.8×10^{-10}
electron to alpha particle mass ratio	m_e/m_α	$1.370\ 933\ 555\ 75(61) \times 10^{-4}$		4.4×10^{-10}
electron charge to mass quotient	$-e/m_e$	$-1.758\ 820\ 12(15) \times 10^{-11}$	$C\ kg^{-1}$	8.6×10^{-8}
electron molar mass $N_A m_e$	$M(e), M_e$	$5.485\ 799\ 0945(24) \times 10^{-7}$	$kg\ mol^{-1}$	4.4×10^{-10}
Compton wavelength $h/m_e c$	λ_C	$2.426\ 310\ 238(16) \times 10^{-12}$	m	6.7×10^{-9}
$\lambda_C/2\pi = \alpha a_0 = \alpha^2/4\pi R\infty$	$\lambda\!\!\!^{-}_C$	$386.159\ 2678(26) \times 10^{-15}$	m	6.7×10^{-9}
classical electron radius $\alpha^2 a_0$	r_e	$2.817\ 940\ 325(28) \times 10^{-15}$	m	1.0×10^{-8}
Thomson cross section $(8\pi/3)\ r_e^2$	σ_e	$0.665\ 245\ 873(13) \times 10^{-28}$	m^2	2.0×10^{-8}
electron magnetic moment	μ_e	$-928.476\ 412(80) \times 10^{-26}$	$J\ T^{-1}$	8.6×10^{-8}
to Bohr magneton ratio	μ_e/μ_B	$-1.001\ 159\ 652\ 1859(38)$		3.8×10^{-12}
to nuclear magneton ratio	μ_e/μ_N	$-1838.281\ 971\ 07(85)$		4.6×10^{-10}
electron magnetic moment anomaly $\lvert\mu_e\rvert/\mu_B - 1$	a_e	$1.159\ 652\ 1859(38) \times 10^{-3}$		3.2×10^{-9}
electron g-factor $-2(1 + a_e)$	g_e	$-2.002\ 319\ 304\ 3718(75)$		3.8×10^{-12}
electron-muon magnetic moment ratio	μ_e/μ_μ	206.766 9894(54)		2.6×10^{-8}
electron-proton magnetic moment ratio	μ_e/μ_p	$-658.210\ 6862(66)$		1.0×10^{-8}
electron to shielded proton magnetic moment ratio (H_2O, sphere, 25°C)	μ_e/μ'_p	$-658.227\ 5956(71)$		1.1×10^{-8}
electron-neutron magnetic moment ratio	μ_e/μ_n	960.920 50(23)		2.4×10^{-7}
electron-deuteron magnetic moment ratio	μ_e/μ_d	$-2143.923\ 493(23)$		1.1×10^{-8}
electron to shielded helion[c] magnetic moment ratio (gas, sphere, 25°C)	μ_e/μ'_h	864.058 255(10)		1.2×10^{-8}
electron gyromagnetic ratio $2\lvert\mu_e\rvert/\hbar$	γ_e	$1.760\ 859\ 74(15) \times 10^{-11}$	$s^{-1}\ T^{-1}$	8.6×10^{-8}
	$\gamma_e/2\pi$	28 024.9532(24)	$MHz\ T^{-1}$	8.6×10^{-8}
		Muon, μ^-		
muon mass	m_μ	$1.883\ 531\ 40(33) \times 10^{-28}$	kg	1.7×10^{-7}
in u, $m_\mu = A_r(\mu)$ u (muon relative atomic mass time u)		0.113 428 9264(30)	u	2.6×10^{-8}
energy equivalent	$m_\mu c^2$	$1.692\ 833\ 60(29) \times 10^{-11}$	J	1.7×10^{-7}
in MeV		105.658 3692(94)	MeV	8.9×10^{-8}

TABLE 1-12 Fundamental Physical Universal Constants (*Continued*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
muon-electron mass ratio	m_μ/m_e	206.768 2838(54)		2.6×10^{-8}
muon-tau mass ratio	m_μ/m_τ	$5.945\ 92(97) \times 10^{-2}$		1.6×10^{-4}
muon-proton mass ratio	m_μ/m_p	0.112 609 5269(29)		2.6×10^{-8}
muon-neutron mass ratio	m_μ/m_n	0.112 454 5175(29)		2.6×10^{-8}
muon molar mass $N_A m_\mu$	$M(\mu), M_\mu$	$0.113\ 428\ 9264(30) \times 10^{-3}$	kg mol^{-1}	2.6×10^{-8}
moun Compton wavelength $h/m_\mu c$	$\lambda_{C,\mu}$	$11.734\ 441\ 05(30) \times 10^{-15}$	m	2.5×10^{-8}
$\lambda_{C,\mu}/2\pi$	$\lambda\!\!\!^{-}_{C,\mu}$	$1.867\ 594\ 298(47) \times 10^{-15}$	m	2.5×10^{-8}
moun magnetic moment	μ_μ	$-4.490\ 447\ 99(40) \times 10^{-26}$	J T^{-1}	8.9×10^{-8}
to Bohr magneton ratio	μ_μ/μ_B	$-4.841\ 970\ 45(13) \times 10^{-3}$		2.6×10^{-8}
to nuclear magneton ratio	μ_μ/μ_N	−8.890 596 98(23)		2.6×10^{-8}
muon magnetic moment anomaly $\lvert\mu_\mu\rvert/(e\hbar/2m_\mu) - 1$	a_μ	$1.165\ 919\ 81(62) \times 10^{-3}$		5.3×10^{-7}
moun g-factor $-2(1 + a_\mu)$	g_μ	−2.002 331 8396(12)		6.2×10^{-10}
moun-proton magnetic moment ratio	μ_μ/μ_p	−3183 345 118(89)		2.8×10^{-8}
		Tau, τ^-		
tau mass[d]	m_τ	$3.167\ 77(52) \times 10^{-27}$	kg	1.6×10^{-4}
in u, $m_\tau = A_r(\tau)$ u (tau relative atomic mass times u)		1.907 68(31)	u	1.6×10^{-4}
energy equivalent	$m_\tau c^2$	$2.847\ 05(46) \times 10^{-10}$	J	1.6×10^{-4}
in MeV		1776.99(29)	MeV	1.6×10^{-4}
tau-electron mass ratio	m_τ/m_e	3477.48(57)		1.6×10^{-4}
tau-muon mass ratio	m_τ/m_μ	16.8183(27)		1.6×10^{-4}
tau-proton mass ratio	m_τ/m_p	1.893 90(31)		1.6×10^{-4}
tau-neutron mass ratio	m_τ/m_n	1.891 29(31)		1.6×10^{-4}
tau molar mass $N_A m_\tau$	$M(\tau), M_\tau$	$1.907\ 68(31) \times 10^{-3}$	kg mol^{-1}	1.6×10^{-4}
tau Compton wavelength $h/m_\tau c$	$\lambda_{C,\tau}$	$0.697\ 72(11) \times 10^{-15}$	m	1.6×10^{-4}
$\lambda_{C,\tau}/2\pi$	$\lambda\!\!\!^{-}_{C,\tau}$	$0.111\ 046(18) \times 10^{-15}$	m	1.6×10^{-4}
		Proton, p		
proton mass	m_p	$1.672\ 621\ 71(29) \times 10^{-27}$	kg	1.7×10^{-7}
in u, $m_p = A_r(p)$ u (proton relative atomic mass times u)		1.007 276 466 88(13)	u	1.3×10^{-10}
energy equivalent	$m_p c^2$	$1.503\ 277\ 43(26) \times 10^{-10}$	J	1.7×10^{-7}
in MeV		938.272 029(80)	MeV	8.6×10^{-8}
proton-electron mass ratio	m_p/m_e	1836.152 672 61(85)		4.6×10^{-10}
proton-muon mass ratio	m_p/m_μ	8.880 243 33(23)		2.6×10^{-8}
proton-tau mass ratio	m_p/m_τ	0.528 012(86)		1.6×10^{-4}
proton-neutron mass ratio	m_p/m_n	0.998 623 478 72(58)		5.8×10^{-10}
proton charge to mass quotient	e/m_p	$9.878\ 833\ 76(82) \times 10^7$	C kg^{-1}	8.6×10^{-8}
proton molar mass $N_A m_p$	$M(p), M_p$	$1.007\ 276\ 466\ 88(13) \times 10^{-3}$	kg mol^{-1}	1.3×10^{-10}
proton Compton wavelength $h/m_p c$	$\lambda_{C,p}$	$1.321\ 409\ 8555(88) \times 10^{-15}$	m	6.7×10^{-9}
$\lambda_{C,p}/2\pi$	$\lambda\!\!\!^{-}_{C,p}$	$0.210\ 308\ 9104(14) \times 10^{-15}$	m	6.7×10^{-9}
proton rms charge radius	R_p	$0.8750(68) \times 10^{-15}$	m	7.8×10^{-3}
proton magnetic moment	μ_p	$1.410\ 606\ 71(12) \times 10^{-26}$	J T^{-1}	8.7×10^{-8}
to Bohr magneton ratio	μ_p/μ_B	$1.521\ 032\ 206(15) \times 10^{-3}$		1.0×10^{-8}
to nuclear magneton ratio	μ_p/μ_N	2.792 847 351(28)		1.0×10^{-8}
proton g-factor $2\mu_p/\mu_N$	g_p	5.585 694 701(56)		1.0×10^{-8}
proton-neutron magnetic moment ratio	μ_p/μ_n	−1.459 898 05(34)		2.4×10^{-7}

(*Continued*)

TABLE 1-12 Fundamental Physical Universal Constants (*Continued*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
shielded proton magnetic moment (H_2O, sphere, 25°C)	μ'_p	$1.410\ 570\ 47(12) \times 10^{-26}$	J T^{-1}	8.7×10^{-8}
to Bohr magneton ratio	μ'_p/μ_B	$1.520\ 993\ 132(16) \times 10^{-3}$		1.1×10^{-8}
to nuclear magneton ratio	μ'_p/μ_N	2.792 775 604(30)		1.1×10^{-8}
proton magnetic shielding correction $1 - \mu'_p/\mu_p$ (H_2O, sphere, 25°C)	σ'_p	$25.689(15) \times 10^{-6}$		5.7×10^{-4}
proton gyromagnetic ratio $2\mu_p/\hbar$	γ_p	$2.675\ 222\ 05(23) \times 10^{8}$	$s^{-1}\ T^{-1}$	8.6×10^{-8}
	$\gamma_p/2\pi$	42.577 4813(37)	MHz T^{-1}	8.6×10^{-8}
shielded proton gyromagnetic ratio $2\mu'_p/\hbar$ (H_2O, sphere, 25°C)	γ'_p	$2.675\ 153\ 33(23) \times 10^{8}$	$s^{-1}\ T^{-1}$	8.6×10^{-8}
	$\gamma'_p/2\pi$	42.576 3875(37)	MHz T^{-1}	8.6×10^{-8}
		Neutron, n		
neutron mass	m_n	$1.674\ 927\ 28(29) \times 10^{-27}$	kg	1.7×10^{-7}
in u, $m_n = A_r(n)$ u (neutron relative atomic mass times u)		1.008 664 915 60(55)	u	5.5×10^{-10}
energy equivalent	m_nc^2	$1.505\ 349\ 57(26) \times 10^{-10}$	J	1.7×10^{-7}
in MeV		939.565 360(81)	MeV	8.6×10^{-8}
neutron-electron mass ratio	m_n/m_e	1838.683 6598(13)		7.0×10^{-10}
neutron-muon mass ratio	m_n/m_μ	8.892 484 02(23)		2.6×10^{-8}
neutron-tau mass ratio	m_n/m_τ	0.528 740(86)		1.6×10^{-4}
neutron-proton mass ratio	m_n/m_p	1.001 378 418 70(58)		5.8×10^{-10}
neutron molar mass $N_A m_n$	$M(n), M_n$	$1.008\ 664\ 915\ 60(55) \times 10^{-3}$	kg mol^{-1}	5.5×10^{-10}
neutron Compton wavelength h/m_nc	$\lambda_{C,n}$	$1.319\ 590\ 9067(88) \times 10^{-15}$	m	6.7×10^{-9}
$\lambda_{C,n}/2\pi$	$\lambda\!\!\!^{-}_{C,n}$	$0.210\ 019\ 4157(14) \times 10^{-15}$	m	6.7×10^{-9}
neutron magnetic moment	μ_n	$-0.966\ 236\ 45(24) \times 10^{-26}$	J T^{-1}	2.5×10^{-7}
to Bohr magneton ratio	μ_n/μ_B	$-1.041\ 875\ 63(25) \times 10^{-3}$		2.4×10^{-7}
to nuclear magneton ratio	μ_n/μ_N	−1.913 042 73(45)		2.4×10^{-7}
neutron g-factor $2\mu_n/\mu_N$	g_n	−3.826 085 46(90)		2.4×10^{-7}
neutron-electron magnetic moment ratio	μ_n/μ_e	$1.040\ 668\ 82(25) \times 10^{-3}$		2.4×10^{-7}
magnetic-proton magnetic moment ratio	μ_n/μ_p	−0.684 979 34(16)		2.4×10^{-7}
neutron to shielded proton magnetic moment ratio (H_2O, sphere, 25°C)	μ_n/μ'_p	−0.684 996 94(16)		2.4×10^{-7}
neutron gyromagnetic ratio $2\lvert\mu_n\rvert/\hbar$	γ_n	$1.832\ 471\ 83(46) \times 10^{8}$	$s^{-1}\ T^{-1}$	2.5×10^{-7}
	$\gamma_n/2\pi$	29.164 6950(73)	MHz T^{-1}	2.5×10^{-7}
		Deuteron, d		
deuteron mass	m_d	$3.343\ 583\ 35(57) \times 10^{-27}$	kg	1.7×10^{-7}
in u, $m_d = A_r(d)$ u (deuteron relative atomic mass times u)		2.013 553 212 70(35)	u	1.7×10^{-10}
energy equivalent	m_dc^2	$3.005\ 062\ 85(51) \times 10^{-10}$	J	1.7×10^{-7}
in MeV		1875.612 82(16)	MeV	8.6×10^{-8}
deuteron-electron mass ratio	m_d/m_e	3670.482 9652(18)		4.8×10^{-10}
deuteron-proton mass ratio	m_d/m_p	1.999 007 500 82(41)		2.0×10^{-10}
deuteron molar mass $N_A m_d$	$M(d), M_d$	$2.013\ 553\ 212\ 70(35) \times 10^{-3}$	kg mol^{-1}	1.7×10^{-10}
deuteron rms charge radius	R_d	$2.1394(28) \times 10^{-15}$	m	1.3×10^{-3}

TABLE 1-12 Fundamental Physical Universal Constants (*Continued*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
deuteron magnetic moment	μ_d	$0.433\,073\,482(38) \times 10^{-26}$	J T^{-1}	8.7×10^{-8}
to Bohr magneton ratio	μ_d/μ_B	$0.466\,975\,4567(50) \times 10^{-3}$		1.1×10^{-8}
to nuclear magneton ratio	μ_d/μ_N	0.857 438 2329(92)		1.1×10^{-8}
deuteron-electron magnetic moment ratio	μ_d/μ_e	$-4.664\,345\,548(50) \times 10^{-4}$		1.1×10^{-8}
deuteron-proton magnetic moment ratio	μ_d/μ_p	0.307 012 2084(45)		1.5×10^{-8}
deuteron-neutron magnetic moment ratio	μ_d/μ_n	−0.448 206 52(11)		2.4×10^{-7}
		Helion, h		
helion mass[c]	m_h	$5.006\,412\,14(86) \times 10^{-27}$	kg	1.7×10^{-7}
in u, $m_h = A_r(h)$ u (helion relative atomic mass times u)		3.014 932 2434(58)	u	1.9×10^{-9}
energy equivalent	$m_h c^2$	$4.499\,538\,84(77) \times 10^{-10}$	J	1.7×10^{-7}
in MeV		2808.391 42(24)	MeV	8.6×10^{-8}
helion-electron mass ratio	m_h/m_e	5495.885 269(11)		2.0×10^{-9}
helion-proton mass ratio	m_h/m_p	2.993 152 6671(58)		1.9×10^{-9}
helion molar mass $N_A m_h$	$M(h), M_h$	$3.014\,932\,2434(58) \times 10^{-3}$	kg mol^{-1}	1.9×10^{-9}
shielded helion magnetic moment (gas, sphere, 25°C)	μ'_h	$-1.074\,553\,024(93) \times 10^{-26}$	J T^{-1}	8.7×10^{-8}
to Bohr magneton ratio	μ'_h/μ_B	$-1.158\,671\,474(14) \times 10^{-3}$		12×10^{-8}
to nuclear magneton ratio	μ'_h/μ_N	−2.127 497 723(25)		12×10^{-8}
shielded helion to proton magnetic moment ratio (gas, sphere, 25°C)	μ'_h/μ_p	−0.761 766 562(12)		1.5×10^{-8}
shielded helion to shielded proton magnetic moment ratio (gas/H_2O, spheres, 25°C)	μ'_h/μ'_p	−0.761 786 1313(33)		4.3×10^{-9}
shielded helion gyromagnetic ratio $2\lvert\mu'_h\rvert/\hbar$ (gas, sphere, 25°C)	γ'_h	$2.037\,894\,70(18) \times 10^{8}$	s^{-1} T^{-1}	8.7×10^{-8}
	$\gamma'_h/2\pi$	32.434 1015(28)	MHz T^{-1}	8.7×10^{-8}
		Alpha particle, α		
alpha particle mass	m_α	$6.644\,6565(11) \times 10^{-27}$	kg	1.7×10^{-7}
in u, $m_\alpha = A_r(\alpha)$ u (alpha particle relative atomic mass times u)		4.001 506 179 149(56)	u	1.4×10^{-11}
energy equivalent	$m_\alpha c^2$	$5.971\,9194(10) \times 10^{-10}$	J	1.7×10^{-7}
in MeV		3727.379 17(32)	MeV	8.6×10^{-8}
alpha particle to electron mass ratio	m_α/m_e	7294.299 5363(32)		4.4×10^{-10}
alpha particle to proton mass ratio	m_α/m_p	3.972 599 689 07(52)		1.3×10^{-10}
alpha particle molar mass $N_A m_\alpha$	$M(\alpha), M_\alpha$	$4.001\,506\,179\,149(56) \times 10^{-3}$	kg mol^{-1}	1.4×10^{-11}
		PHYSICO-CHEMICAL		
Avogadro constant	N_A, L	$6.022\,1415(10) \times 10^{23}$	mol^{-1}	1.7×10^{-7}
atomic mass constant $m_u = {}^1/_{12} m(^{12}C) = 1$ u = 10^{-3} kg mol^{-1}/N_A	m_u	$1.660\,538\,86(28) \times 10^{-27}$	kg	1.7×10^{-7}
energy equivalent	$m_u c^2$	$1.492\,417\,90(26) \times 10^{-10}$	J	1.7×10^{-7}
in MeV		931.494 043(80)	MeV	8.6×10^{-8}
Faraday constant[e] $N_A e$	F	96 485.3383(83)	C mol^{-1}	8.6×10^{-8}
molar Planck constant	$N_A h$	$3.990\,312\,716(27) \times 10^{-10}$	J s mol^{-1}	6.7×10^{-9}
	$N_A hc$	0.119 626 565 72(80)	J m mol^{-1}	6.7×10^{-9}

(*Continued*)

TABLE 1-12 Fundamental Physical Universal Constants (*Continued*)

Quantity	Symbol	Numerical value	Unit	Relative std. uncert. u_r
molar gas constant	R	8.314 472(15)	J mol^{-1} K^{-1}	1.7×10^{-6}
Boltzmann constant R/N_A	k	$1.380\,6505(24) \times 10^{-23}$	J K^{-1}	1.8×10^{-6}
in eV K^{-1}		$8.617\,343(15) \times 10^{-5}$	eV K^{-1}	1.8×10^{-6}
	k/h	$2.083\,6644(36) \times 10^{10}$	Hz K^{-1}	1.7×10^{-6}
	k/hc	69.503 56(12)	m^{-1} K^{-1}	1.7×10^{-6}
molar volume of ideal gas RT/p				
$T = 273.15$ K, $p = 101.325$ kpa	V_m	$22.413\,996(39) \times 10^{-3}$	m^3 mol^{-1}	1.7×10^{-6}
Loschmidt constant N_A/V_m	n_0	$2.686\,7773(47) \times 10^{25}$	m^{-3}	1.8×10^{-6}
$T = 273.15$ K, $p = 100$ kpa	V_m	$22.710\,981(40) \times 10^{-3}$	m^3 mol^{-1}	1.7×10^{-6}
Sackur-Tetrode constant (absolute entropy constant)[f] $^5/_2 +$ in $[2\pi m_u kT_1/h^2)^{3/2} kT_1/p_0]$				
$T_1 = 1$ K, $p_0 = 100$ kPa	S_0/R	−1.151 7047(44)		3.8×10^{-6}
$T_1 = 1$ K, $p_0 = 101.325$ kPa		−1.164 8677(44)		3.8×10^{-6}
Stefan-Boltzmann constant $(\pi^2/60)\ k^4/\hbar^3\ c^2$	σ	$5.670\,400(40) \times 10^{-8}$	W m^{-2} K^{-4}	7.0×10^{-6}
first radiation constant $2\pi hc^2$	c_1	$3.741\,771\,38(64) \times 10^{-16}$	W m^2	1.7×10^{-7}
first radiation constant for spectral radiance $2hc^2$	c_{1L}	$1.191\,042\,82(20) \times 10^{-16}$	W m^2 sr^{-1}	1.7×10^{-7}
second radiation constant hc/k	c_2	$1.438\,7752(25) \times 10^{-2}$	m K	1.7×10^{-6}
Wien displacement law constant $b = \lambda_{max} T = c_2/4.965\,114\,231\ldots$	b	$2.897\,7685(51) \times 10^{-3}$	m K	1.7×10^{-6}

Source: *CODATA recommended values of the fundamental physical constants: 2002; Peter J. Mohr and Barry N. Taylor; *Rev, Mod, Phys.* January 2005, vol. 77, no. 1, pp. 1–107.

[a] Value recommended by the Particle Data Group (Hagiwara et al., 2002).

[b] Based on the ratio of the masses of the W and Z bosons m_W/m_Z recommended by the Particle Data Group (Hagiwara et al., 2002). The value for $\sin^2\theta_W$ they recommend, which is based on a particular variant of the modified minimal subtraction ($\overline{MS}$) scheme, is $\sin^2\hat{\theta}_W(Mz) = 0.231\,24(24)$.

[c] The hellion, symbol h, is the nucleus of the ^{3}He atom.

[d] This and all other values involving m_τ are based on the value of $m_\tau c^2$ in MeV recommended by the Particle Data Group (Hagiwara et al., 2002), but with a standard uncertainty of 0.29 MeV rather than the quoted uncertainty of −0.26 MeV, +0.29 MeV.

[e] The numerical value of F to be used in coulometric chemical measurements is 96 485.336(16) $[1.7 \times 10^{-7}]$ when the relevant current is measured in terms of representations of the volt and ohm based on the Josephson and quantum Hall effects and the internationally, adopted conventional values of the Josephson and von Klitzing constants K_{J-90} and R_{K-90}.

[f] The entropy of an ideal monoatomic gas of relative atomic mass A_r is given by $S = S_0 + {}^3/_2\ R \ln A_r - R \ln (p/p_0) + {}^5/_2\ R \ln (T/K)$.

1.15 NUMERICAL VALUES

Extensive use is made in electrical engineering of the constants π and ϵ and of the numbers 2 and 10, the latter in logarithmic units and number systems. Table 1-14 lists functions of these numbers to 9 or 10 significant digits. In most engineering applications (except those involving the difference of large, nearly equal numbers), five significant digits suffice. The use of the listed values in computations with electronic hand calculators will suffice in most cases to produce results more than adequate for engineering work.

1.16 CONVERSION FACTORS

The increasing use of the metric system in British and American practice has generated a need for extensive tables of multiplying factors to facilitate conversions from and to the SI units. Tables 1-15 through 1-28 list these conversion factors.

Table	Quantity	SI unit	Subtabulation	Basis of grouping
1-15	Length	meter	1-15A	Units decimally related to one meter
			1-15B	Units less than one meter
			1-15C	Units greater than one meter
			1-15D	Other length units
1-16	Area	square meter	1-16A	Units decimally related to one square meter
			1-16B	Nonmetric area units
			1-16C	Other area units
1-17	Volume/capacity	cubic meter	1-17A	Units decimally related to one cubic meter
			1-17B	Nonmetric volume units
			1-17C	U.S. liquid capacity measures
			1-17D	British liquid capacity measures
			1-17E	U.S. and U.K. dry capacity measures
			1-17F	Other volume and capacity units
1-18	Mass	kilogram	1-18A	Units decimally related to one kilogram
			1-18B	Less than one pound-mass
			1-18C	One pound-mass and greater
			1-18D	Other mass units
1-19	Time	second	1-19A	One second and less
			1-19B	One second and greater
			1-19C	Other time units
1-20	Velocity	meter per second		
1-21	Density	kilogram per cubic meter	1-21A	Units decimally related to one kilogram per cubic meter
			1-21B	Nonmetric density units
			1-21C	Other density units
1-22	Force	newton		
1-23	Pressure	pascal	1-23A	Units decimally related to one pascal
			1-23B	Units decimally related to one kilogram-force per square meter
			1-23C	Units expressed as heights of liquid
			1-23D	Nonmetric pressure units
1-24	Torque/bending moment	newton meter		
1-25	Energy/work	joule	1-25A	Units decimally related to one joule
			1-25B	Units less than 10 joules
			1-25C	Units greater than 10 joules
1-26	Power	watt	1-26A	Units decimally related to one watt
			1-26B	Nonmetric power units
1-27	Temperature	kelvin		
1-28	Light	candela per square meter	1-28A	Luminance units
		lux	1-28B	Illuminance units

Statements of Equivalence. To avoid ambiguity, the conversion tables have been arranged in the form of statements of equivalence, that is, each unit listed at the left-hand edge of each table is stated to be equivalent to a multiple or fraction of each of the units to the right in the table. For example, the uppermost line of Table 1-15B represents the following statements:

Column 2. 1 meter is equal to 1.093 613 30 yards

Column 3. 1 meter is equal to 3.280 839 89 feet

Column 4. 1 meter is equal to 39.370 078 7 inches

Column 5. 1 meter is equal to $3.937\ 007\ 87 \times 10^4$ mils

Column 6. 1 meter is equal to $3.937\ 007\ 87 \times 10^7$ microinches

TABLE 1-13 Derived Energy Equivalents

[Derived from the relations $E = mc^2 = hc/\lambda = h\nu = kT$, and based on the 2002 CODATA adjustment of the values of the constants; 1 eV = (e/C) J, 1 u = m_u = ½ m (^{12}C) = 10^{-3} kg mol^{-1}/N_A, and $E_h = 2R\infty\, hc = \alpha^2\, m_e c^2$ is the Hartree energy (hartree).]

	Relevant unit			
	J	kg	m^{-1}	Hz
1 J	(1 J) = 1 J	(1 J)/c^2 = $1.112\,650\,056\ldots \times 10^{-17}$ kg	(1 J)/hc = $5.034\,117\,20(86) \times 10^{24}$ m^{-1}	(1 J)/h = $1.509\,190\,37(26) \times 10^{33}$ Hz
1 kg	(1 kg)c^2 = $8.987\,551\,787\ldots \times 10^{16}$ J	(1 kg) = 1 kg	(1 kg) c/h = $4.524\,438\,91(77) \times 10^{41}$ m^{-1}	(1 kg) c^2/h = $1.356\,392\,66(23) \times 10^{50}$ Hz
1 m^{-1}	(1 m^{-1}) hc = $1.986\,445\,61(34) \times 10^{-25}$ J	(1 m^{-1}) h/c = $2.210\,218\,81(38) \times 10^{-42}$ kg	(1 m^{-1}) = 1m^{-1}	(1 m^{-1}) c = 299 792 458 Hz
1 Hz	(1 Hz) h = $6.626\,0693(11) \times 10^{-34}$ J	(1 Hz) h/c^2 = $7.372\,4964(13) \times 10^{-51}$ kg	(1 Hz)/c = $3.335\,640\,951\ldots \times 10^{-9}$ m^{-1}	(1 Hz) = 1 Hz
1 K	(1 K) k = $1.380\,6505(24) \times 10^{-23}$ J	(1 K) k/c^2 = $1.536\,1808(27) \times 10^{-40}$ kg	(1 K)k/hc = 69.503 56(12) m^{-1}	(1 K) k/h = $2.083\,6644(36) \times 10^{10}$ Hz
1 eV	(1 eV) = $1.602\,176\,53(14) \times 10^{-19}$ J	(1 eV) /c^2 = $1.782\,661\,81(15) \times 10^{-36}$ kg	(1 eV)/hc = 8.065 544 45 (69) $\times 10^5$ m^{-1}	(1 eV)/h = $2.417\,989\,40(21) \times 10^{14}$ Hz
1 u	(1 u)c^2 = $1.492\,417\,90(26) \times 10^{-10}$ J	(1 u) = $1.660\,538\,86(28) \times 10^{-27}$ kg	(1 u)c/h = $7.513\,006\,608(50) \times 10^{14}$ m^{-1}	(1 u) c^2/h = $2.252\,342\,718(15) \times 10^{23}$ Hz
1 E_h	(1 E_h) = $4.359\,744\,17(75) \times 10^{-18}$ J	(1 E_h)/c^2 = $4.850\,869\,60\,(83) \times 10^{-35}$ kg	(1 E_h)/hc = $2.194\,746\,313\,705(15) \times 10^7$ m^{-1}	(1 E_h)/h = $6.579\,683\,920\,721(44) \times 10^{15}$ Hz

	Relevant unit			
	K	eV	u	E_h
1 J	(1 J)/k = $7.242\,963(13) \times 10^{22}$ K	(1 J) = $6.241\,509\,47(53) \times 10^{18}$ eV	(1 J)/c^2 = $6.700\,5361(11) \times 10^9$ u	(1 J) = $2.293\,712\,57(39) \times 10^{17}$ E_h
1 kg	(1 kg)c^2/k = $6.509\,650(11) \times 10^{39}$ K	(1 kg)c^2 = $5.609\,588\,96(48) \times 10^{35}$ eV	(1 kg)= $6.022\,1415(10) \times 10^{26}$ u	(1 kg)c^2 = $2.061\,486\,05(35) \times 10^{34}$ E_h
1 m^{-1}	(1 m^{-1})hc/k = $1.438\,7752(25) \times 10^{-2}$ K	(1 m^{-1})hc = $1.239\,841\,91(11) \times 10^{-6}$ eV	(1 m^{-1})h/c = $1.331\,025\,0506(89) \times 10^{-15}$ u	(1 m^{-1})hc = $4.556\,335\,252\,760(30) \times 10^{-8}$ E_h
1 Hz	(1 Hz)h/k = $4.799\,2374(84) \times 10^{-11}$ K	(1 Hz)h = $4.135\,667\,43(35) \times 10^{-15}$ eV	(1 Hz)h/c^2 = $4.439\,821\,667(30) \times 10^{-24}$ u	(1 Hz)h = $1.519\,829\,846\,006(10) \times 10^{-16}$ E_h
1 K	(1 K) = 1 K	(1 K)k = $8.617\,343(15) \times 10^{-5}$ eV	(1 K)k/c^2 = $9.251\,098(16) \times 10^{-14}$ u	(1 K)k = $3.166\,8153(55) \times 10^{-6}$ E_h
1 eV	(1 eV)/k = $1.160\,4505(20) \times 10^4$ K	(1 eV) = 1 eV	(1 eV)/c^2 = $1.073\,544\,171(92) \times 10^{-9}$ u	(1 eV) = $3.674\,932\,45(31) \times 10^{-2}$ E_h
1 u	(1 u)c^2/k = $1.080\,9527(19) \times 10^{13}$ K	(1 u)c^2 = 931.494 043(80) $\times 10^6$ eV	(1 u)= 1 u	(1 u)c^2 = $3.423\,177\,686(23) \times 10^7$ E_h
1 E_h	(1 E_h)/k = $3.157\,7465(55) \times 10^5$ K	(1 E_h) = 27.211 3845(23) eV	(1 E_h)/c^2 = $2.921\,262\,323(19) \times 10^{-8}$ u	(1 E_h) = 1 E_h

TABLE 1-14 Numerical Values Used in Electrical Engineering

Functions of π:

π = 3.141 592 654
$1/\pi$ = 0.318 309 886
π^2 = 9.869 604 404
$\sqrt{\pi}$ = 1.772 453 851
$\pi/180°$ = 0.017 453 293 (= radians per degree)
$180°/\pi$ = 57.295 779 51 (= degrees per radian)

Functions of ϵ:

ϵ = 2.718 281 828
$1/\epsilon$ = 0.367 879 441
$1 - 1/\epsilon$ = 0.632 120 559
ϵ^2 = 7.389 056 096
$\sqrt{\epsilon}$ = 1.648 721 271

(*Continued*)

TABLE 1-14 Numerical Values Used in Electrical Engineering (*Continued*)

Logarithms to the base 10:

$\log_{10} \pi = 0.497\ 149\ 873$
$\log_{10} \epsilon = 0.434\ 294\ 482$
$\log_{10} 2 = 0.301\ 029\ 996$
$\log_{10} x = (\ln x)(0.434\ 294\ 482) = (\log_2 x)(0.301\ 029\ 996)$

Natural logarithms (to the base ϵ):

$\ln \pi = 1.144\ 729\ 886$
$\ln 2 = 0.693\ 147\ 181$
$\ln 10 = 2.302\ 585\ 093$
$\ln x = (\log_{10} x)(2.302\ 585\ 093) = (\log_2 x)(0.693\ 147\ 181)$

Logarithms to the base 2:

$\log_2 \pi = 1.651\ 496\ 130$
$\log_2 \epsilon = 1.442\ 695\ 042$
$\log_2 10 = 3.321\ 928\ 096$
$\log_2 x = (\log_{10} x)(3.321\ 928\ 096) = (\ln x)(1.442\ 695\ 042)$

Powers of 2:

$2^5 = 32$
$2^{10} = 1024$
$2^{15} = 32{,}768$
$2^{20} = 1{,}048{,}576$
$2^{25} = 33{,}554{,}432$
$2^{30} = 1{,}073{,}741{,}824$
$2^{40} = 1.099\ 511\ 628 \times 10^{12}$
$2^{50} = 1.125\ 899\ 907 \times 10^{15}$
$2^{100} = 1.267\ 650\ 601 \times 10^{30}$

Logarithmic units:

Power ratio	Current or voltage ratio	Decibels*	Nepers†
1	1	0	0
2	1.414 214	3.010 300	0.346 574
3	1.732 051	4.771 213	0.549 306
4	2	6.020 600	0.693 147
5	2.236 068	6.989 700	0.804 719
10	3.162 278	10	1.151 293
15	3.872 983	11.760 913	1.354 025

Values of $2^{(2N)}$:

Value of N	Value of $2^{(2N)}$
1	4
2	16
3	256
4	65,536
5	4,294,967,296
6	$1.844\ 674\ 407 \times 10^{19}$
7	$3.402\ 823\ 668 \times 10^{38}$
8	$1.157\ 920\ 892 \times 10^{77}$
9	$1.340\ 780\ 792 \times 10^{154}$
10	$1.797\ 693\ 132 \times 10^{308}$

*The decibel is defined for power ratios only. It may be applied to current or voltage ratios only when the resistances through which the currents flow or across which the voltages are applied are equal.

†The neper is defined for current and voltage ratios only. It may be applied to power ratios only when the respective resistances are equal.

TABLE 1-15 Length Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of length is the meter.

A. Length units decimally related to one meter

	Meters (m)	Kilometers (km)	Decimeters (dm)	Centimeters (cm)	Millimeters (mm)	Micrometers (μm)	Nanometers (nm)	Ångströms (Å)
1 meter =	**1**	**0.001**	**10**	**100**	**1 000**	**1 000 000**	$\mathbf{10^9}$	$\mathbf{10^{10}}$
1 kilometer =	**1 000**	**1**	**10 000**	**100 000**	**1 000 000**	$\mathbf{10^9}$	$\mathbf{10^{12}}$	$\mathbf{10^{13}}$
1 decimeter =	**0.1**	**0.000 1**	**1**	**10**	**100**	**100 000**	$\mathbf{10^8}$	$\mathbf{10^8}$
1 centimeter =	**0.01**	**0.000 01**	**0.1**	**1**	**10**	**10 000**	$\mathbf{10^7}$	$\mathbf{10^8}$
1 millimeter =	**0.001**	$\mathbf{10^{-6}}$	**0.01**	**0.1**	**1**	**1 000**	**1 000 000**	$\mathbf{10^7}$
1 micrometer (micron) =	$\mathbf{10^{-6}}$	$\mathbf{10^{-9}}$	**0.000 01**	**0.000 1**	**0.001**	**1**	**1 000**	**10 000**
1 nanometer =	$\mathbf{10^{-9}}$	$\mathbf{10^{-12}}$	$\mathbf{10^{-8}}$	$\mathbf{10^{-7}}$	$\mathbf{10^{-6}}$	**0.001**	**1**	**10**
1 ångström =	$\mathbf{10^{-10}}$	$\mathbf{10^{-13}}$	$\mathbf{10^{-9}}$	$\mathbf{10^{-8}}$	$\mathbf{10^{-7}}$	**0.000 1**	**0.1**	**1**

B. Nonmetric length units less than one meter

	Meters (m)	Yards (yd)	Feet (ft)	Inches (in)	Mils (mil)	Microinches (μin)
1 meter =	**1**	1.093 613 30	3.280 839 89	39.370 078 7	$3.937\,007\,87 \times 10^4$	$3.937\,007\,87 \times 10^7$
1 yard =	**0.914 4**	**1**	**3**	**36**	**36 000**	$\mathbf{3.6 \times 10^7}$
1 foot =	**0.304 8**	**1/3** = 0.333 3	**1**	**12**	**12 000**	$\mathbf{1.2 \times 10^7}$
1 inch =	**0.025 4**	**1/36** = 0.027 7	**1/12** = 0.083 3	**1**	**1 000**	**1 000 000**
1 mil =	$\mathbf{2.54 \times 10^{-5}}$	$2.77\overline{7} \times 10^{-5}$	$8.33\overline{3} \times 10^{-5}$	**0.001**	**1**	**1 000**
1 microinch =	$\mathbf{2.54 \times 10^{-8}}$	$2.77\overline{7} \times 10^{-8}$	$8.33\overline{3} \times 10^{-8}$	$\mathbf{10^{-8}}$	**0.001**	**1**

C. Nonmetric length units greater than one meter (with equivalents in feet)

	Meters (m)	Rods (rd)	Statute miles (mi)	Nautical miles (nmi)	Astronomical units (AU)	Parsecs (pc)	Feet (ft)
1 meter =	**1**	0.198 838 78	$6.213\,711\,92 \times 10^{-4}$	$5.399\,568\,04 \times 10^{-4}$	$6.684\,491\,98 \times 10^{-12}$	$3.240\,733\,17 \times 10^{-17}$	3.280 839 89
1 rod =	**5.029 2**	**1**	**0.003 125**	$2.715\,550\,76 \times 10^{-3}$	$3.361\,764\,71 \times 10^{-11}$	$1.629\,829\,53 \times 10^{-16}$	**16.5**
1 statute mile =	**1 609.344**	**320**	**1**	0.868 976 24	$1.075\,764\,71 \times 10^{-8}$	$5.215\,454\,50 \times 10^{-14}$	**5 280**
1 nautical mile =	**1 852**	368.249 423	1.150 779 45	**1**	$1.237\,967\,91 \times 10^{-8}$	$6.001\,837\,80 \times 10^{-14}$	6 076.115 48
1 astronomical unit* =	$\mathbf{1.496 \times 10^{11}}$	$2.974\,628\,17 \times 10^{10}$	92 957 130.3	80 777 537.8	**1**	$4.848\,136\,82 \times 10^{-6}$	$4.908\,136\,48 \times 10^{11}$
1 parsec =	$3.085\,721\,50 \times 10^{16}$	$6.135\,611\,02 \times 10^{15}$	$1.917\,378\,44 \times 10^{13}$	$1.666\,156\,32 \times 10^{13}$	206 264.806	**1**	$1.012\,375\,82 \times 10^{17}$
1 foot =	**0.304 8**	$0.060\,6\overline{06}$	$1.893\,9\overline{39} \times 10^{-4}$	$1.645\,788\,33 \times 10^{-4}$	$2.037\,433\,16 \times {}^{-12}$	$9.877\,754\,72 \times 10^{-18}$	**1**

D. Other length units
1 cable = **720** feet = **219.456** meters
1 cable (U.K.) = **608** feet = **185.318 4** meters
1 chain (engineers') = **100** feet = **30.48** meters
1 chain (surveyors') = **66** feet = **20.116 8** meters
1 fathom = **6** feet = **1.828 8** meters
1 fermi = **1** femtometer = $\mathbf{10^{-15}}$ meter
1 foot (U.S. Survey) = 0.304 800 6 meter
1 furlong = **660** feet = **201.168** meters
1 hand = **4** inches = **0.101 6** meter
1 league (international nautical) = 3 nautical miles = **5 556** meters
1 league (statute) = **3** statute miles = **4 828.032** meters
1 league (U.K. nautical) = 5 559.552 meters
1 light-year = $9.460\,895\,2 \times 10^{15}$ meters (= distance traveled by light in vacuum in one sidereal year)
1 link (engineers') = **1** foot = **0.304 8** meter
1 link (surveyors') = **7.92** inches = **0.201 168** meter
1 micron = **1** micrometer = $\mathbf{10^{-6}}$ meter
1 millimicron = **1** nanometer = $\mathbf{10^{-9}}$ meter
1 myriameter = **10 000** meters
1 nautical mile (U.K.) = 1 853.184 meters
1 pale = **1** rod = **5.029 2** meters
1 perch (linear) = **1** rod = **5.029 2** meters
1 pica = **1/6** inch (approx.) = $4.217\,518 \times 10^{-3}$ meter
1 point = **1/72** inch (approx.) = $3.514\,598 \times 10^{-4}$ meter
1 span = **9** inches = **0.228 6** meter

*As defined by the International Astronomical Union.

TABLE 1-16 Area Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of area is the square meter.

A. Area units decimally related to one square meter

	Square meters $(m)^2$	Square kilometers $(km)^2$	Hectares (square hectometers) $(hm)^2$	Square centimeters $(cm)^2$	Square millimeters $(mm)^2$	Square micrometers $(\mu m)^2$	Barns (b)
1 square meter =	**1**	**10^{-6}**	**0.000 1**	**10 000**	**1 000 000**	**10^{12}**	**10^{28}**
1 square kilometer =	**1 000 000**	**1**	**100**	**10^{10}**	**10^{12}**	**10^{18}**	**10^{34}**
1 hectare =	**10 000**	**0.01**	**1**	**10^{8}**	**10^{10}**	**10^{16}**	**10^{32}**
1 square centimeter =	**0.000 1**	**10^{-10}**	**10^{-8}**	**1**	**100**	**10^{8}**	**10^{24}**
1 square millimeter =	**10^{-6}**	**10^{-12}**	**10^{-10}**	**0.01**	**1**	**10^{6}**	**10^{22}**
1 square micrometer =	**10^{-12}**	**10^{-18}**	**10^{-16}**	**10^{-8}**	**10^{-6}**	**1**	**10^{16}**
1 barn =	**10^{-28}**	**10^{-34}**	**10^{-32}**	**10^{-24}**	**10^{-22}**	**10^{-16}**	**1**

B. Nonmetric area units (with square meter equivalents)

	Square meters $(m)^2$	Square statute miles $(mi)^2$	Acres (acre)	Square rods $(rd)^2$	Square yards $(yd)^2$	Square feet $(ft)^2$	Square inches $(in)^2$	Circular mils (cmil)
1 square meter =	**1**	$3.861\ 021\ 59 \times 10^{-7}$	$2.471\ 053\ 82 \times 10^{-4}$	$3.953\ 686\ 10 \times 10^{-2}$	1.195 990 05	10.763 910 4	1 550.003 10	$1.973\ 525\ 24 \times 10^{9}$
1 square statute mile =	2 589 988.1	**1**	**640**	**102 400**	**3 097 600**	**27 878 400**	$4.014\ 489\ 60 \times 10^{9}$	$5.111\ 406\ 91 \times 10^{15}$
1 acre =	4 046.856 11	**1/640 = 0.001 562 5**	**1**	**160**	**4 840**	**43 560**	**6 272 640**	$7.986\ 573\ 30 \times 10^{12}$
1 square rod =	25.292 852 6	**$9.765\ 625 \times 10^{-6}$**	**1/160 − 0.006 25**	**1**	**30.25**	**272.25**	**39 204**	$4.991\ 608\ 31 \times 10^{10}$
1 square yard =	**0.836 127 36**	$3.228\ 305\ 79 \times 10^{-7}$	$2.066\ 115\ 70 \times 10^{-4}$	$3.305\ 785\ 12 \times 10^{-2}$	**1**	**9**	**1 296**	$1.650\ 118\ 45 \times 10^{9}$
1 square foot =	**0.092 903 04**	$3.587\ 006\ 43 \times 10^{-8}$	$2.295\ 684\ 11 \times 10^{-5}$	$3.673\ 094\ 58 \times 10^{-3}$	**1/9** = 0.111 1̲1̲1̲	**1**	**144**	$1.833\ 464\ 95 \times 10^{8}$
1 square inch =	**$6.451\ 6 \times 10^{-4}$**	$2.490\ 976\ 69 \times 10^{-10}$	$1.594\ 225\ 08 \times 10^{-7}$	$2.550\ 760\ 13 \times 10^{-5}$	$7.716\ 049\ 38 \times 10^{-4}$	**1/144** = 0.006 944 4̲4̲	**1**	$1.273\ 239\ 55 \times 10^{6}$
1 circular mil =	$5.067\ 074\ 79 \times 10^{-10}$	$1.956\ 408\ 51 \times 10^{-16}$	$1.252\ 101\ 45 \times 10^{-13}$	$2.003\ 362\ 32 \times 10^{-11}$	$6.060\ 171\ 01 \times 10^{-10}$	$5.454\ 153\ 91 \times 10^{-9}$	$7.853\ 981\ 63 \times 10^{-7}$	**1**

Exact conversions are:
1 acre = **4 046.856 422 4** square meters
1 square mile = **2 589 988.110 336** square meters

C. Other area units

1 are = **100** square meters
1 centiare (centare) = **1** square meter
1 perch (area) = **1** square rod = **30.25** square yards = 25.292 852 6 square meters
1 rod = **40** square rods = 1 011.714 11 square meters
1 section = **1** square statute mile = 2 589 988.1 square meters
1 township = **36** square statute miles = 93 239 572 square meters

TABLE 1-17 Volume and Capacity Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of volume is the cubic meter.

A. Volume units decimally related to one cubic meter

	Cubic meters (steres) $(m)^3$	Cubic decimeters $(dm)^3$	Cubic centimeters $(cm)^3$	Liters (L)	Centiliters (cL)	Milliliters (mL)	Microliters (μL)
1 cubic meter =	**1**	**1 000**	**1 000 000**	**1 000**	**100 000**	**1 000 000**	**10^9**
1 cubic decimeter =	**0.001**	**1**	**1 000**	**1**	**100**	**1 000**	**1 000 000**
1 cubic centimeter =	**0.000 001**	**0.001**	**1**	**0.001**	**0.1**	**1**	**1 000**
1 liter =	**0.001**	**1**	**1 000**	**1**	**100**	**1 000**	**1 000 000**
1 centiliter =	**0.000 01**	**0.01**	**10**	**0.01**	**1**	**10**	**10 000**
1 milliliter =	**0.000 001**	**0.001**	**1**	**0.001**	**0.1**	**1**	**1 000**
1 microliter =	**10^{-9}**	**0.000 001**	**0.001**	**0.000 001**	**0.000 1**	**0.001**	**1**

B. Nonmetric volume units (with cubic meter and liter equivalents)

	Cubic meters (steres) $(m)^3$	Liters (L)	Cubic inches $(in)^3$	Cubic feet $(ft)^3$	Cubic yards $(yd)^3$	Barrels (U.S.A.) (bbl)	Acre-Feet (acre-ft)	Cubic miles $(mi)^3$
1 cubic meter =	**1**	**1 000**	6.102 374 41 × 10^4	35.314 66$\underline{6}$	1.307 950 62	6.289 810 97	8.107 131 94 × 10^{-4}	2.399 127 59 × 10^{-10}
1 liter =	**0.001**	**1**	61.023 744 1	0.035 314 6$\underline{6}$	1.307 950 62 × 10^{-3}	6.289 810 97 × 10^{-3}	8.107 131 93 × 10^{-7}	2.399 127 59 × 10^{-13}
1 cubic inch =	**1.638 706 4 × 10^{-5}**	**1.638 706 4 × 10^{-2}**	**1**	**1/1 728** = 5.787 037 0$\underline{3}$ × 10^{-4}	**1/46 656** = 2.143 347 05 × 10^{-5}	1.030 715 32 × 10^{-4}	1.328 520 90 × 10^{-8}	3.931 465 73 × 10^{-15}
1 cubic foot =	2.831 684 66 × 10^{-2}	**28.316 846 592**	**1 728**	**1**	**1/27** = 0.037 0$\underline{37}$	0.178 107 61	**1/43 560** = 2.295 684 11 × 10^{-5}	6.793 572 78 × 10^{-12}
1 cubic yard =	0.764 554 86	764.55 485 8	**46 656**	**27**	**1**	4.808 905 38	6.198 347 11 × 10^{-4}	1.834 264 65 × 10^{-10}
1 barrel (U.S.) =	0.158 987 29	158.987 294	**9 702**	5.614 583 33	0.207 947 53	**1**	1.288 930 98 × 10^{-4}	3.814 308 05 × 10^{-11}
1 acre-foot =	1.233 481 84	1.233 481 84 × 10^6	7.527 168 00 × 10^7	**43 560**	1 613 333 3$\underline{3}$	7 758.367 34	**1**	2.959 280 30 × 10^{-7}
1 cubic mile =	4.168 181 83 × 10^9	4.168 181 83 × 10^{12}	2.543 580 61 × 10^{14}	**1.471 979 52 × 10^{11}**	**5.451 776 × 10^9**	26.217 074 9 × 10^9	**3 379 200**	**1**

TABLE 1-17 Volume and Capacity Conversion Factors (*Continued*)

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of volume is the cubic meter.

C. United States liquid capacity measures (with liter equivalents)

	Liters (L)	Gallons (U.S. gal)	Quarts (U.S. qt)	Pints (U.S. pt)	Gills (U.S. gi)	Fluid ounces (U.S. floz)	Fluidrams (U.S. fldr)	Minims (U.S. minim)
1 liter =	**1**	0.264 172 05	1.056 688	2.113 376	8.453 506	33.814 023	270.512 18	16 230.73
1 gallon, U.S. =	3.785 411 8	**1**	**4**	**8**	**32**	**128**	**1 024**	**61 440**
1 quart, U.S. =	**0.946 352 946**	**1/4 = 0.25**	**1**	**2**	**8**	**32**	**256**	**15 360**
1 pint, U.S. =	0.473 176 5	**1/8 = 0.125**	**1/2 = 0.5**	**1**	**4**	**16**	**128**	**7 680**
1 gill, U.S. =	0.118 294 1	**1/32 = 0.031 25**	**1/8 = 0.125**	**1/4 = 0.25**	**1**	**4**	**32**	**1 920**
1 fluid ounce, U.S. =	$2.957\ 353 \times 10^{-2}$	**1/128 = 0.007 812 5**	**1/32 = 0.031 25**	1/16 = 0.062 5	**1/4 = 0.25**	**1**	**8**	**480**
1 fluidram, U.S. =	$3.696\ 691\ 2 \times 10^{-3}$	**1/102 4 = $9.765\ 625 \times 10^{-4}$**	**1/256 = $3.906\ 25 \times 10^{-3}$**	**1/128 = 0.007 812 5**	**1/32 = 0.031 25**	**1/8 = 0.125**	**1**	**60**
1 minim, U.S. =	$6.161\ 152 \times 10^{-5}$	**1/61 440 =** $1.627\ 604\ \underline{16} \times 10^{-5}$	**1/15 360 =** $6.510\ 416\ \underline{66} \times 10^{-5}$	**1/7 680 =** $1.302\ 083\ 3\underline{3} \times 10^{-4}$	**1/1 920 =** $5.208\ 333\ \underline{3} \times 10^{-4}$	**1/480 =** $2.083\ 333\ \underline{3} \times 10^{-3}$	**1/60 =** 0.016 666 6	**1**

D. British Imperial liquid capacity measures (with liter equivalents)

	Liters (L)	Gallons (U.K. gal)	Quarts (U.K. qt)	Pints (U.K. pt)	Gills (U.K. gi)	Fluid ounces (U.K. floz)	Fluidrams (U.K. fldr)	Minims (U.K. minim)
1 liter =	**1**	0.219 969 2	0.879 876 6	1.759 753	7.039 018	35.195 06	281.560 5	16 893.63
1 gallon, U.K. =	4.546 092	**1**	**4**	**8**	**32**	**160**	**1 280**	**76 800**
1 quart, U.K. =	1.136 523	**1/4 = 0.25**	**1**	**2**	**8**	**40**	**320**	**19 200**
1 pint, U.K. =	0.568 261 5	**1/8 = 0.125**	**1/2 = 0.5**	**1**	**4**	**20**	**160**	**9 600**
1 gill, U.K. =	0.142 065 4	**1/32 = 0.031 25**	**1/8 = 0.125**	**1/4 = 0.25**	**1**	**5**	**40**	**2 400**
1 fluid ounce, U.K. =	$2.841\ 307 \times 10^{-2}$	**1/160 = 0.006 25**	**1/40 = 0.025**	**1/20 = 0.05**	**1/5 = 0.2**	**1**	**8**	**480**
1 fluidram, U.K. =	$3.551\ 634 \times 10^{-3}$	**1/1280 = $7.812\ 5 \times 10^{-4}$**	**1/320 = 0.003 125**	**1/160 = 0.006 25**	**1/40 = 0.025**	**1/8 = 0.125**	**1**	**60**
1 minim, U.K. =	$5.919\ 391 \times 10^{-5}$	**1/76 800 =** $1.302\ 083\ 3\underline{3} \times 10^{-5}$	**1/19 200 =** $5.208\ 333\ 3\underline{3} \times 10^{-5}$	**1/9 600 =** $1.041\ 666\ 6\underline{6} \times 10^{-4}$	**1/2 400 =** $4.166\ 666\ 6\underline{6} \times 10^{-4}$	**1/480 =** $2.083\ 333\ 3\underline{3} \times 10^{-3}$	**1/60 =** 0.016 666 66	**1**

E. United States and British dry capacity measures (with liter equivalents)

		U.S. dry measures				British dry measures			
	Liters (L)	Bushels (U.S. bu)	Pecks (U.S. peck)	Quarts (U.S. qt)	Pints (U.S. pt)	Bushels (U.K. bu)	Pecks (U.K. peck)	Quarts (U.K. qt)	Pints (U.K. pt)
1 liter =	**1**	0.028 377 59	0.113 510 37	0.908 082 99	1.816 165 98	0.027 496 1	0.109 984 6	0.879 876 6	1.759 753 4
1 bushel, U.S. =	35.239 070	**1**	**4**	**32**	**64**	0.968 938 7	3.875 754 9	31.006 04	62.012 08
1 peck, U.S. =	8.809 767 5	**1/4 = 0.25**	**1**	**8**	**16**	0.242 234 7	0.968 938 7	7.751 509	15.503 02
1 quart, U.S. =	1.101 220 9	**1/32 = 0.031 25**	**1/8 = 0.125**	**1**	**2**	0.030 279 34	0.121 117 3	0.968 938 7	1.937 878
1 pint, U.S. =	0.550 610 5	**1/64 = 0.015 625**	**1/16 = 0.062 5**	**1/2 = 0.5**	**1**	0.015 139 67	0.060 558 67	0.484 469 3	0.968 938 7
1 bushel, U.K. =	36.368 73	1.032 057	4.128 228	33.025 82	66.051 65	**1**	**4**	**32**	**64**
1 peck, U.K. =	9.092 182	0.258 014 3	1.032 057	8.256 456	16.512 91	**1/4 = 0.25**	**1**	**8**	**16**
1 quart, U.K. =	1.136 523	0.032 251 78	0.129 007 1	1.032 057	2.064 114.2	**1/32 = 0.031 25**	**1/8 = 0.125**	**1**	**2**
1 pint, U.K. =	0.568 261 4	0.016 125 89	0.064 503 6	0.516 028 4	1.032 057	**1/64 = 0.015 625**	**1/64 = 0.062 5**	**1/2 = 0.5**	**1**

Exact conversion: 1 dry pint, U.S. = **33.600 312 5** enblc inches

F. Other volume and capacity units

1 barrel, U.S. (used for petroleum, etc.) = **42** gallons = 0.158.987 296 cubic meter
1 barrel ("old barrel") = **31.5** gallons = 0.119 240 cubic meter
1 board foot = **144** cubic inches = $2.359\,737 \times 10^{-3}$ cubic meter
1 cord = **128** cubic feet = 3.624 556 cubic meters
1 cord foot = **16** cubic feet = 0.453 069.5 cubic meter
1 cup = **8** fluid ounces, U.S. = $2.365\,882 \times 10^{-4}$ cubic meter
1 gallon (Canadian, liquid) = $4.546\,090 \times 10^{-3}$ cubic meter
1 perch (volume) = 24.75 cubic feet = 0.700 842 cubic meter
1 stere = **1** cubic meter
1 tablespoon = **0.5** fluid ounce, U.S. = $1.478\,677 \times 10^{-5}$ cubic meter
1 teaspoon = **1/6** fluid ounce, U.S. = $4.928\,922 \times 10^{-6}$ cubic meter
1 ton (register ton) = **100** cubic feet = 2.831 684 66 cubic meters

TABLE 1-18 Mass Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of mass is the kilogram.

A. Mass units decimally related to one kilogram

	Kilograms (kg)	Tonnes (metric tons)	Grams (g)	Decigrams (dg)	Centigrams (cg)	Milligrams (mg)	Micrograms (μg)
1 kilogram =	**1**	**0.001**	**1 000**	**10 000**	**100 000**	**1 000 000**	$\mathbf{10^9}$
1 tonne =	**1 000**	**1**	**1 000 000**	$\mathbf{10^7}$	$\mathbf{10^8}$	$\mathbf{10^9}$	$\mathbf{10^{12}}$
1 gram =	**0.001**	**0.000 001**	**1**	**10**	**100**	**1 000**	**1 000 000**
1 decigram =	**0.000 1**	$\mathbf{10^{-7}}$	**0.1**	**1**	**10**	**100**	**100 000**
1 centigram =	**0.000 01**	$\mathbf{10^{-8}}$	**0.01**	**0.1**	**1**	**10**	**10 000**
1 milligram =	**0.000 001**	$\mathbf{10^{-9}}$	**0.001**	**0.01**	**0.1**	**1**	**1 000**
1 microgram =	$\mathbf{10^{-9}}$	$\mathbf{10^{-12}}$	**0.000 001**	**0.000 01**	**0.000 1**	**0.001**	**1**

B. Nonmetric mass units less than one pound-mass (with gram equivalents)

	Grams (g)	Avoirdupois ounces-mass (oz_m, avdp)	Troy ounces-mass (oz_m, troy)	Avoirdupois drams (dr avdp)	Apothecary drams (dr apoth)	Pennyweights (dwt)	Grains (grain)	Scruples (scruple)
1 gram =	**1**	0.035 273 962	0.032 150 747	0.564 383 39	0.257 205 97	0.643 014 93	15.432 358 4	0.771 617 92
1 avdp ounce-mass =	28.349 523 1	**1**	0.911 458 33	**16**	7.291 666 66	18.227 166 7	**437.5**	**21.875**
1 troy ounce-mass =	31.103 476 8	1.097 142 86	**1**	17.554 285 7	**8**	**20**	**480**	**24**
1 avdp dram =	1.771 845 20	**1/16 = 0.062 5**	0.056 966 15	**1**	0.455 729 17	1.139 322 92	**27.343 75**	**1.367 187 5**
1 apothecary dram =	3.887 934 58	0.137 142 857	**1/8 = 0.125**	2.194 285 70	**1**	**2.5**	**60**	**3**
1 pennyweight =	1.555 173 83	0.054 863 162	**1/20 = 0.05**	0.877 714 28	**1/2.5 = 0.4**	**1**	**24**	**1.2**
1 grain =	**0.064 798 91**	**1/437.5** = 2.285 714 29 × 10^{-3}	**1/480** = 0.002 0833 33	3.657 142 85 × 10^{-2}	**1/60** = 0.016 666 66	**1/24** = 0.041 666 66	**1**	**0.05**
1 scrople =	1.295 078 20	4.571 428 58 × 10^{-2}	**1/24** = 0.041 666 66	0.731 428 57	**1/3** = 0.333 333 33	**5/6** = 0.833 333 33	**20**	**1**

C. Nonmetric mass units of one pound-mass and greater (with kilogram equivalents)

	Kilograms (kg)	Long tons (long ton)	Short tons (short ton)	Long hundredweights (long cwt)	Short hundredweights (short cwt)	Slugs (slug)	Avoirdupois pounds-mass (lb_m, avdp)	Troy pounds-mass (lb_m, troy)
1 kilogram =	**1**	9.842 065 28 × 10^{-1}	1.102 311 31 × 10^{-3}	1.968 411 31 × 10^{-2}	2.204 622 62 × 10^{-2}	0.068 521 77	2.204 622 62	2.679 228 89
1 long ton =	1 016.046 9	**1**	**1.12**	**20**	**22.4**	69.621 329	**2 240**	2 722 222 22
1 short ton =	**907.184 74**	**200/224** = 0.892 857 14	**1**	**4 000/224** = 17.857 142 9	**20**	62.161 901	**2 000**	2 430.555 55
1 long hundredweight =	50.802 345 4	**0.05**	**0.056**	**1**	**1.12**	3.481 066 4	**112**	136.111 11$\underline{1}$
1 short hundredweight =	**45.359 237**	**10/224** = 0.044 642 86	**0.05**	**100/112** = 0.892 857 14	**1**	3.108 095 0	**100**	121.527 7$\underline{77}$
1 slug =	14.593 903	0.014 363 41	0.016 087 02	0.287 268 3	0.321 740 5	**1**	32.174 05	39.100 406
1 avdp pound-mass =	**0.453 592 37**	**1/2 240** = 4.464 285 71 × 10^{-1}	**0.000 5**	**1/1 12** = 8.928 571 43 × 10^{-3}	**0.01**	3.108 095 0 × 10^{-2}	**1**	1.215 277 7$\underline{77}$
1 troy pound-mass =	0.373 241 72	3.673 469 37 × 10^{-1}	4.114 285 70 × 10^{-1}	7.346 938 79 × 10^{-3}	8.228 571 45 × 10^{-3}	0.025 575 18	0.822 857 14	**1**

Exact conversions: 1 long ton = **1 016.046 908 8** kilograms
1 troy pound-mass = **0.373 241 721 6** kilogram

D. Other mass units

1 assay ton = 29.166 667 grams
1 carat (metric) = **200** milligrams
1 carat (troy weight) = $\mathbf{3^1/_6}$ grains = 205.196 55 milligrams
1 myriagram = **10** kilograms
1 quintal = **100** kilograms
1 stone = **14** pounds, avdp = **6.350 293 18** kilograms

TABLE 1-19 Time Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of time is the second.

A. Time units of one second and less

	Seconds (s)	Milliseconds (ms)	Microseconds (μs)		Picoseconds (ps)
1 second =	**1**	**1 000**	**1 000 000**	$\mathbf{10^9}$	$\mathbf{10^{12}}$
1 millisecond =	**0.001**	**1**	**1 000**	**1 000 000**	$\mathbf{10^9}$
1 microsecond =	**0.000 001**	**0.001**	**1**	**1 000**	**1 000 000**
1 nanosecond =	$\mathbf{10^{-9}}$	**0.000 001**	**0.001**	**1**	**1 000**
1 picosecond =	$\mathbf{10^{-12}}$	$\mathbf{10^{-9}}$	**0.000 001**	**0.001**	**1**

B. Time units of one second and greater

	Mean solar seconds (s)	Mean solar minutes (min)	Mean solar hours (h)	Mean solar days (d)	Mean solar weeks (w)	Calendar (Gregorian) year (yr)
1 second =	**1**	**1/60** = 0.016 666 $\underline{6}$	**1/3 600** = 0.000 277 $\underline{7}$	**1/86 400** = $1.157\ 407\ \underline{407} \times 10^{-5}$	**1/604 800** = $1.653\ 439\ 15 \times 10^{-6}$	$3.168\ 873\ 85 \times 10^{-8}$
1 minute =	**60**	**1**	**1/60** = 0.016 666 $\underline{6}$	**1/1 440** = 0.000 694 $\underline{44}$	**1/10 080** = $9.920\ 634\ 92 \times 10^{-5}$	$1.901\ 324\ 31 \times 10^{-6}$
1 hour =	**3 600**	**60**	**1**	**1/24** = 0.041 666 $\underline{6}$	**1/168** = $5.952\ 380\ 95 \times 10^{-3}$	$1.140\ 794\ 50 \times 10^{-4}$
1 day =	**86 400**	**1 440**	**24**	**1**	**1/7 = 0.142 857 14**	$2.737\ 907\ 00 \times 10^{-3}$
1 week =	**604 800**	**10 080**	**168**	**7**	**1**	$1.916\ 534\ 90 \times 10^{-2}$
1 calendar year = (Gregorian)	31 556 952	525 949.2	8 765.82	365.242 5	52.117 5	**1**

NOTES: The conventional calendar year of 365 days can be used in rough calculations only; the modern calendar is based on the Gregorian year of 365.2425 mean solar days, the value chosen by Pope Gregory XIII in 1582. This value requires that a leap-year day be introduced every four years as February 29, except that centennial years (1900, 2000, etc) are leap years only when divisible by 400. The remaining difference between the Gregorian year and the tropical year (see below) introduces an error of 1 day in 3300 years.

The tropical year is the interval between successive vernal equinoxes and has been defined by the International Astronomical Union for noon of January 1, 1900 as 31 556 925.974 7 seconds = 365.242 198 79 mean solar days. The tropical year decreases by approximately 5.3 milliseconds per year. The sidereal year is the interval between successive returns of the sun to the direction of the same star. Sidereal time units, given in Table 1-18C, are used primarily in astronomy. The SI second, defined by the atomic process of the cesium atom, is equal to the mean solar second within the limits of their definition.

C. Other time units

1 decade = **10** Gregorian years
1 fortnight = **14** days = **1 209 600** seconds
1 century = **100** Gregorian years
1 millennium = **1000** Gregorian years
1 sidereal year = 366.256 4 sidereal days = 31 558 149.8 seconds
1 sidereal day = 86 164.091 seconds
1 sidereal hour = 3 590.170 seconds
1 sidereal minute = 59.836 17 seconds
1 sidereal second = 0.997 269 6 second
1 shake = $\mathbf{10^{-8}}$ seconds

TABLE 1-20 Velocity Conversion Factors

The SI unit of velocity is the meter per second.

	Meters per second (m/s)	Kilometers per hour (km/h)	Statute miles per hour (mi/h)	Knots (kn)	Feet per minute (ft/min)	Feet per second (ft/s)	Inches per second (in/s)
1 meter per second =	**1**	**3.6**	2.236 936 29	1.943 844 49	196.850 394	3.280 839 89	39.370 0787
1 kilometer per hour =	**1/3.6** = 0.277 77$\underline{7}$	**1**	0.621 371 19	0.539 956 80	54.680 664 9	0.911 344 42	10.936 133 0
1 statute mile per hour =	**0.447 04**	**1.609 344**	**1**	0.868 976 24	**88**	**88/60** = 1.466 66$\underline{6}$	**88/5 = 17.6**
1 knot =	0.514 44$\underline{4}$	**1.852**	1.150 779 45	**1**	101.268 592	1.687 780 99	20.253 718 4
1 foot per minute =	**0.005 08**	**0.018 288**	0.011 3$\underline{6}$3	$9.874\ 730\ 01 \times 10^{-3}$	**1**	**1/60** = 0.016 66$\underline{6}$	**1/5 = 0.2**
1 foot per second =	**0.304 8**	**1.097 28**	0.681 8$\underline{1}$8	0.592 483 80	**60**	**1**	**12**
1 inch per second =	**0.025 4**	**0.091 44**	0.056 8$\underline{1}$8	0.049 373 65	**5**	**1/12** = 0.083 33$\underline{3}$	**1**

NOTE: The velocity of light in vacuum, c = 299 792 458 meters per second = 670 616 629 statute miles per hour
= 186 282.397 statute miles per second
= 0.983 571 056 feet per nanosecond

Other velocity units

1 foot per hour = $8.466\ 667 \times 10^{-5}$ meter per second
1 statute mile per minute = **26.822 4** meters per second
1 statute mile per second = **1 609.344** meters per second

TABLE 1-21 Density Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of density is the kilogram per cubic meter.

A. Density units decimally related to one kilogram per cubic meter

	Kilograms per cubic meter (kg/m^3)	Tonnes per cubic meter (t/m^3)	Grams per cubic meter (g/m^3)	Grams per liter (g/L)	Milligrams per liter (mg/L)	Micrograms per milliliter ($\mu g/mL$)
1 kilogram per cubic meter =	**1**	**0.001**	**1 000**	**1**	**1 000**	**1 000**
1 tonne per cubic meter =	**1 000**	**1**	**1 000 000**	**1 000**	**1 000 000**	**1 000 000**
1 gram per cubic meter =	**0.001**	**0.000 001**	**1**	**0.001**	**1**	**1**
1 gram per liter =	**1**	**0.001**	**1 000**	**1**	**1 000**	**1 000**
1 milligram per liter =	**0.001**	**0.000 001**	**1**	**0.001**	**1**	**1**
1 microgram per milliliter =	**0.001**	**0.000 001**	**1**	**0.001**	**1**	**1**

B. Nonmetric density units (with kilogram per cubic meter equivalents)

	Kilograms per cubic meter (kg/m^3)	Short tons per cubic mile (short tons/mi^3)	Avoirdupois pounds per acrefoot (lb avdp/acre-ft)	Avoirdupois pounds per cubic foot (lb avdp/ft^3)	Avoirdupois pounds per cubic inch (lb avdp/in^3)	Avoirdupois ounces per U.S. quart (oz advp/U.S. qt)	Avoirdupois drams per U.S. fluid ounce (dr advp/U.S. floz)	Grains per U.S. fluid ounce (grain/U.S. floz)
1 kilogram per cubic meter =	**1**	4 594 934	2 719.362 0	$6.242\ 796\ 1 \times 10^{-2}$	$3.612\ 729\ 20 \times 10^{-5}$	$3.338\ 161\ 6 \times 10^{-2}$	$1.669\ 080\ 82 \times 10^{-2}$	0.456 389 28
1 short ton per cubic mile =	$2.176\ 451\ 9 \times 10^{-7}$	**1**	$5.918\ 560\ 5 \times 10^{-4}$	$1.358\ 7145 \times 10^{-8}$	$7.862\ 931\ 3 \times 10^{-12}$	$7.265\ 348\ 2 \times 10^{-9}$	$3.632\ 674\ 1 \times 10^{-9}$	$9.933\ 0931\ 1 \times 10^{-8}$
1 avdp pound per acrefoot =	$3.677\ 333\ 2 \times 10^{-4}$	1 689.600 0	**1**	$2.295\ 684\ 1 \times 10^{-5}$	$1.328\ 520\ 9 \times 10^{-8}$	$1.227\ 553\ 2 \times 10^{-5}$	$6.137\ 766\ 2 \times 10^{-6}$	$1.678\ 295\ 5 \times 10^{-4}$
1 avdp pound per cubic foot =	16.018 463 4	73 598 976	**43 560**	**1**	**1/1 728** = $5.787\ 03\underline{7}\ \underline{03} \times 10^{-4}$	0.534 722 $\underline{2}$	0.267 361 $\underline{1}$	7.310 655 0
1 avdp pound per cubic inch =	27 679.905	$1.271\ 790\ 4 \times 10^{11}$	**75 271 680**	**1 728**	**1**	**924**	**462**	12 632.812
1 avdp ounce per U.S. quart =	29.956 608	$1.376\ 395\ 5 \times 10^{8}$	81 462.86	1.870 130 0	$1.082\ 251\ 1 \times 10^{-3}$	**1**	**0.5**	13.671 874
1 avdp dram per U.S. fluid ounce =	59.913 216	$2.752\ 793\ 0 \times 10^{8}$	162 925.72	3.740 259 8	$2.164\ 502\ 3 \times 10^{-3}$	**2**	**1**	27.343 748
1 grain per U.S. fluid ounce =	2.191 111 9	10 067 357	5 958.426 3	0.136 786 65	$7.915\ 894\ 0 \times 10^{-5}$	0.073 142 86	0.036 571 43	**1**

C. Other density units

1 grain per gallon, U.S. = 17.118 06 grams per cubic meter
1 gram per cubic centimeter = **1 000** kilograms per cubic meter
1 avdp ounce per gallon, U.S. = 7.489 152 kilograms per cubic meter
1 avdp ounce per cubic inch = 1 729.994 kilograms per cubic meter
1 avdp pound per gallon, U.S. = 119.826 4 kilograms per cubic meter
1 slug per cubic foot = 515.379 kilograms per cubic meter
1 long ton per cubic yard = 1 328.939 kilograms per cubic meter

TABLE 1-22 Force Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of force is the newton (N).

	Newtons (N)	Kips (kip)	Slugs-force ($slug_f$)	Kilograms-force (kilopond) (kg_f)	Avoirdupois pounds-force (lb_f avdp)	Avoirdupois ounces-force (oz_f advp)	Poundals (pdl)	Dynes (dyn)
1 newton =	**1**	$2.248\,089\,43 \times 10^{-4}$	$6.987\,275\,24 \times 10^{-3}$	0.101 971 62	0.224 808 94	3.596 943 09	7.233 014 2	**100 000**
1 kip =	444 8.221 62	**1**	31.080 949	453.592 370	**1 000**	**16 000**	32 174.05	444 822 162
1 slug-force =	143.117 305	0.032 174 05	**1**	14.593 903	32.174 05	514 784 80	1 035.169 5	14 311 730
1 kilogram force (kilopond) =	**9.806 650**	$2.204\,622\,62 \times 10^{-3}$	$6.852\,176\,3 \times 10^{-2}$	**1**	2.204 622 62	35.273 961 9	70 931 638 4	**980 665**
1 avdp pound force =	4.448 221 62	**0.001**	$3.108\,094\,88 \times 10^{-2}$	0.453 592 37	**1**	**16**	32.174 05	444 822.162
1 avdp ounce force =	0.278 013 85	**1/16 000 = 0.000 062 5**	$1.942\,559\,30 \times 10^{-3}$	$2.834\,952\,3 \times 10^{-2}$	**1/16 = 0.062 5**	**1**	2.010 878 03	27 801.385
1 poundal =	0.138 254 95	$3.108\,094\,9 \times 10^{-5}$	$9.660\,253\,9 \times 10^{-4}$	0.140 980 81	0.031 080 95	0.497 295 18	**1**	13 825.495
1 dyne =	**0.000 01**	$2.248\,089\,43 \times 10^{-8}$	$6.987\,275\,24 \times 10^{-8}$	$1.019\,716\,21 \times 10^{-6}$	$2.248\,089\,43 \times 10^{-6}$	$3.596\,943\,10 \times 10^{-5}$	$7.233\,014\,2 \times 10^{-5}$	**1**

The exact conversion is 1 avdp pound-force = **4.448 221 615 260 5** newtons.

TABLE 1-23 Pressure/Stress Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of pressure or stress is the pascal (Pa).

A. Pressure units decimally related to one pascal

	Pascals (Pa)	Bars (bar)	Decibars (dbar)	Millibars (mbar)	Dynes per square centimeter (dyn/cm^2)
1 pascal =	**1**	**0.000 01**	**0.000 1**	**0.01**	**10**
1 bar =	**100 000**	**1**	**10**	**1 000**	**1 000 000**
1 decibar =	**10 000**	**0.1**	**1**	**100**	**100 000**
1 millibar =	**100**	**0.001**	**0.01**	**1**	**1 000**
1 dyne per square centimeter =	**0.1**	**0.000 001**	**0.000 01**	**0.001**	**1**

B. Pressure units decimally related to one kilogram-force per square meter (with pascal equivalents)

	Kilograms-force per square meter (kg_f/m^2)	Kilograms-force per square centimeter (kg_f/cm^2)	Kilograms-force per square millimeter (kg_f/mm^2)	Grams-force per square centimeter (g_f/cm^2)	Pascals (Pa)
1 kilogram-force per square meter =	**1**	**0.000 1**	**0.000 001**	**0.1**	**9.806 65**
1 kilogram-force per square centimeter =	**10 000**	**1**	**0.01**	**1 000**	**98 066.5**
1 kilogram-force per square millimeter =	**1 000 000**	**100**	**1**	**100 000**	**9 806 650**
1 gram-force per square centimeter =	**10**	**0.001**	**0.000 01**	**1**	**98.066 5**
1 pascal =	0.101 971 62	$1.019\,7162 \times 10^{-5}$	$1.019\,716\,2 \times 10^{-7}$	$1.019\,716\,2 \times 10^{-2}$	1

NOTE: **1** atmosphere (technical) = 1 kilogram-force per square centimeter = **98 066.5** pascals.

C. Pressure units expressed as heights of liquid (with pascal equivalents)

	Millimeters of mercury at 0°C (mmHg, 0°C)	Centimeters of mercury at 60°C (cmHg, 60°C)	Inches of mercury at 32°F (inHg, 32°F)	Inches of mercury at 60°F (inHg, 60°F)	Centimeters of water at 4°C (cmH_2O, 4°C)	Inches of water at 60°F (inH_2O, 60°F)	Feet of water at 39.2°F (ftH_2O, 39.2°F)	Pascals (Pa)
1 millimeter of mercury, 0°C =	**1**	0.100 282	0.039 370 1	0.039 481 3	1.359 548	0.535 775 6	0.044 604 6	133.322 4
1 centimeter of mercury, 60°C =	9.971 830	**1**	0.392 591 9	0.393 700 8	13.557 18	5.342 664	0.444 789 5	1 329.468
1 inch of mercury, 32°F =	**25.4**	2.547 175	**1**	1.002 824 8	34.532 52	13.608 70	1.132 957	3 386.389
1 inch of mercury, 60°C =	25.328 45	**2.54**	0.997 183 1	**1**	34.435 25	13.570 37	1.129 765	3 376.85
1 centimeter of water, 4°C =	0.735 539	0.073 762	0.028 958	0.029 040 0	**1**	0.394 083 8	0.032 808 4	98.063 8
1 inch of water, 60°F =	1.866 453	0.187 173	0.073 482	0.073 690 0	2.537 531	**1**	0.083 252 4	248.840
1 foot of water, 39.2°F =	22.419 2	2.248 254	0.882 646	0.885 139	30.479 98	12.011 67	**1**	2 988.98
1 pascal =	$7.500\,615 \times 10^{-3}$	$7.521\,806 \times 10^{-4}$	$2.952\,998 \times 10^{-4}$	$2.961\,34 \times 10^{-4}$	$1.019\,74 \times 10^{-2}$	$4.018\,65 \times 10^{-3}$	$3.345\,62 \times 10^{-4}$	**1**

NOTE: 1 torr = 1 millimeter of mercury at 0°C = 133.322 4 pascals.

D. Nonmetric pressure units (with pascal equivalents)

	Atmospheres (atm)	Avoirdupois pounds-force per square inch (lb/in^2)	Avoirdupois pounds-force per square foot (lb_f/ft^2, avdp)	Poundals per square foot (pdl/ft^2)	Pascals (Pa)
1 atmosphere =	**1**	14.695 95	2 116.217	68 087.24	**101 325**
1 avdp pound-force per square inch =	$6.804\,60 \times 10^{-2}$	**1**	**144**	4 633.063	6 894.757
1 avdp pound-force per square foot =	$4.725\,414 \times 10^{-4}$	**1/144** = 0.006 94$\underline{4}$	**1**	32.174 05	47.880 26
1 poundal per square foot =	$1.468\,704 \times 10^{-5}$	$2.158\,399 \times 10^{-4}$	0.031 080 9	**1**	1.488 164
1 pascal =	$9.869\,233 \times 10^{-6}$	$1.450\,377 \times 10^{-4}$	0.020 885 4	0.671 968 9	**1**

NOTE: 1 normal atmosphere = 760 torr = **101 325** pascals.

TABLE 1-24 Torque/Bending Moment Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of torque is the newton-meter (N · m).

	Newton-meters (N · m)	Kilogram-force-meters (kg_f · m)	Avoirdupois pound-force-feet (lb_f · ft, avdp)	Avoirdupois pound-force-inches (lb_f · in, avdp)	Avoirdupois ounce-force-inches (oz_f · in, avdp)	Dyne-centimeters (dyne · cm)
1 newton-meter =	**1**	0.101 971 6	0.737 562 1	8.850 748 1	141.611 9	**10 000 000**
1 kilogram-force-meter =	**9.806 65**	**1**	7.233 013	86.796 16	1 388.739	**98 066 500**
1 avdp pound-force-foot =	1.355 818	0.138 255 0	**1**	**12**	**192**	13 558 180
1 avdp pound-force-inch =	0.112 984 8	$1.152\ 124 \times 10^{-2}$	**1/12** = 0.083 33$\underline{3}$	**1**	**16**	1 129 848
1 avdp ounce-force-inch =	$7.061\ 552 \times 10^{-3}$	$7.200\ 779 \times 10^{-4}$	**1/192** = 0.005 208 $\underline{3}$	**1/16 = 0.062 5**	**1**	70 615.52
1 dyne-centimeter =	$\mathbf{10^{-7}}$	$1.017\ 716 \times 10^{-8}$	$7.375\ 621 \times 10^{-8}$	$8.850\ 748 \times 10^{-7}$	$1.416\ 119 \times 10^{-5}$	**1**

TABLE 1-25 Energy/Work Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of energy and work is the joule (J).

A. Energy/work units decimally related to one joule

	Joules (J)	Megajoules (MJ)	Kilojoules (kJ)	Millijoules (mJ)	Microjoules (μJ)	Ergs (erg)
1 joule =	**1**	**0.000 001**	**0.001**	**1 000**	**1 000 000**	$\mathbf{10^7}$
1 megajoule =	**1 000 000**	**1**	**1 000**	$\mathbf{10^9}$	$\mathbf{10^{12}}$	$\mathbf{10^{13}}$
1 kilojoule =	**1 000**	**0.001**	**1**	**1 000 000**	$\mathbf{10^9}$	$\mathbf{10^{10}}$
1 millijoule =	**0.001**	$\mathbf{10^{-9}}$	$\mathbf{10^{-6}}$	**1**	**1 000**	**10 000**
1 microjoule =	**0.000 001**	$\mathbf{10^{-12}}$	$\mathbf{10^{-9}}$	**0.001**	**1**	**10**
1 erg =	$\mathbf{10^{-7}}$	$\mathbf{10^{-13}}$	$\mathbf{10^{-10}}$	**0.000 1**	**0.1**	**1**

NOTE: 1 watt-second = 1 joule.

B. Energy/work units less than ten joules (with joule equivalents)

	Joules (J)	Foot-poundals (ft · pdl)	Foot-pounds-force (ft · lb_f)	Calories (International Table) (cal, IT)	Calories (thermochemical) (cal, thermo)	Electronvolts (eV)
1 joule =	**1**	23.730 36	0.737 562 1	0.238 845 9	0.239 005 7	$6.241\ 46 \times 10^{18}$
1 foot-poundal =	$4.214\ 011 \times 10^{-2}$	**1**	$3.108\ 095 \times 10^{-2}$	$1.006\ 499 \times 10^{-2}$	$1.007\ 173 \times 10^{-2}$	$2.630\ 16 \times 10^{17}$
1 foot-pound-force =	1.355 818	32.174 05	**1**	0.323 831 6	0.324 048 3	$8.462\ 28 \times 10^{18}$
1 calorie (Int. Tab.) =	**4.186 8**	99.854 27	3.088 025	**1**	1.000 669	$2.613\ 17 \times 10^{19}$
1 calorie (thermo) =	**4.184**	99.287 83	3.085 960	0.999 331 2	**1**	$2.611\ 43 \times 10^{19}$
1 electronvolt =	$1.602\ 19 \times 10^{-18}$	$3.802\ 05 \times 10^{-18}$	$1.181\ 71 \times 10^{-19}$	$3.826\ 77 \times 10^{-20}$	$3.829\ 33 \times 10^{-20}$	**1**

C. Energy/work units greater than ten joules (with joule equivalents)

	Joules (J)	British thermal units, International Table (Btu, IT)	British thermal units, thermochemical (Btu, thermo)	Kilowatthours (kWh)	Horsepower-hours, electrical (hp · h, elec)	Kilocalories, International Table (kcal, IT)	Kilocalories, thermochemical (kcal, thermo)
1 joule =	**1**	$9.478\ 170 \times 10^{-4}$	$9.484\ 516\ 5 \times 10^{-4}$	$\mathbf{1/(3.6 \times 10^6)}$ $\mathbf{2.777 \times 10^{-7}}$	$3.723\ 562 \times 10^{-7}$	$2.388\ 459 \times 10^{-4}$	$2.390\ 057\ 4 \times 10^{-4}$
1 British thermal unit, Int. Tab. =	1 055.056	**1**	1.000 669	$2.930\ 711\ 1 \times 10^{-4}$	$3.928\ 567 \times 10^{-4}$	0.251 995 8	0.252 164 4
1 British thermal unit (thermo) =	1 054.35	0.999 331	**1**	$2.928\ 745 \times 10^{-4}$	$03.925\ 938 \times 10^{-4}$	0.251 827 2	0.251 995 7
1 kilowatthour =	**3 600 000**	3 412.141	3 414.426	**1**	**1/0.746** = 1.340 482 6	859.845 2	860.420 7
1 horsepower hour, electrical =	**2 685 600**	2 545.457	2 547.162	**0.746**	**1**	641.444 5	641.873 8
1 kilocalorie, Int. Tab. =	**4 186.8**	3.968 320	3.970 977	**0.001 163**	$1.558\ 981 \times 10^{-3}$	**1**	1.000 669
1 kilocalorie, thermochemical =	**4 184**	3.965 666	3.968 322	0.001 162 2	$1.557\ 938\ 6 \times 10^{-3}$	0.999 331	**1**

The exact conversion is 1 British thermal unit, International Table = **1 055.055 852 62** joules.

TABLE 1-26 Power Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.) The SI unit of power is the watt (W).

A. Power units decimally related to one watt

	Watts (W)	Megawatts (MW)	Kilowatts (kW)	Milliwatts (mW)	Microwatts (μW)	Picowatts (pW)	Ergs per second (ergs/s)
1 watt =	**1**	**0.000 001**	**0.001**	**1 000**	**1 000 000**	$\mathbf{10^9}$	$\mathbf{10^7}$
1 megawatt =	**1 000 000**	**1**	**1 000**	$\mathbf{10^9}$	$\mathbf{10^{12}}$	$\mathbf{10^{15}}$	$\mathbf{10^{13}}$
1 kilowatt =	**1 000**	**0.001**	**1**	**1 000 000**	$\mathbf{10^9}$	$\mathbf{10^{12}}$	$\mathbf{10^{10}}$
1 milliwatt =	**0.001**	$\mathbf{10^{-9}}$	**0.000 001**	**1**	**1 000**	**1 000 000**	**10 000**
1 microwatt =	**0.000 001**	$\mathbf{10^{-12}}$	$\mathbf{10^{-9}}$	**0.001**	**1**	**1 000**	**10**
1 picowatt =	$\mathbf{10^{-9}}$	$\mathbf{10^{-15}}$	$\mathbf{10^{-12}}$	**0.000 001**	**0.001**	**1**	**0.01**
1 erg per second =	$\mathbf{10^{-7}}$	$\mathbf{10^{-13}}$	$\mathbf{10^{-10}}$	**0.000 1**	**0.1**	**100**	**1**

NOTE: 1 watt = 1 joule per second (J/s).

B. Nonmetric power units (with watt equivalents)

	British thermal units (International Table) per hour (Btu/hr, IT)	British thermal units (thermochemical) per minute (Btu/min, thermo)	Avoirdupois foot-pounds-force per second (ft · lb_p/s avdp)	Kilocalories per minute (thermochemical) (kcal/min, thermo)	Kilocalories per second (International Table) (kcal/s, IT)	Horsepower (electrical) (hp, elec)	Horsepower (mechanical) (hp, mech)	Watts (W)
1 British thermal unit (Int. Tab.) per hour =	**1**	0.016 677 8	0.216 158 1	4.202 740 5 × 10^{-3}	6.999 883 1 × 10^{-5}	3.928 567 0 × 10^{-4}	3.930 148 0 × 10^{-4}	0.293 071 1
1 British thermal unit (thermo) per minute =	59.959 853	**1**	12.960 810	0.251 995 7	4.197 119 5 × 10^{-3}	0.023 555 6	0.023 565 1	17.572 50
1 foot-pound-force per second =	4.626 242 6	0.077 155 7	**1**	0.019 442 9	3.238 315 7 × 10^{-4}	1.817 450 4 × 10^{-3}	**1/550** = 1.818 18$\underline{1\ 8}$ × 10^{-3}	1.355 818
1 kilocalorie per minute (thermo) =	237.939 98	3.968 321 7	51.432 665	**1**	0.016 655 5	0.093 476 3	0.093 513 9	69.733 333
1 kilocalorie per second (Int. Tab.) =	14 285.953	238.258 64	3 088.025 1	60.040 153	**1**	5.612 332 4	5.614 591 1	**4 186.800**
1 horsepower (electrical) =	2 545.457 4	42.452 696	550.221 34	10.697 898	0.178 179 0	**1**	1.000 402 4	**746**
1 horsepower (mechanical) =	2 544.433 4	42.435 618	**550**	10.693 593	0.178 107 4	0.999 597 7	**1**	745.699 9
1 watt =	3.412 141 3	0.056 907 1	0.737.562 1	0.014 340 3	2.388 459 0 × 10^{-4}	**1/746** = 1.340 482 6 × 10^{-3}	1.341 022 0 × 10^{-3}	**1**

NOTE: The horsepower (mechanical) is defined as a power equal to **550** foot-pounds-force per second.
Other units of horsepower are:
1 horsepower (boiler) = 9 809.50 watts
1 horsepower (metric) = 735.499 watts
1 horsepower (water) = 746.043 watts
1 horsepower (U.K.) = 745.70 watts
1 ton (refrigeration) = 3 516.8 watts

TABLE 1-27 Temperature Conversions
(Conversions in **boldface** type are exact. Continuing decimals are underlined.)

Celsius (°C) °C = 5(°F–32)/9	Fahrenheit (°F) °F = [9(C°)/5] + 32	Absolute (K) K = °C + 273.15
–273.15	**–459.67**	**0**
–200	**–328**	**73.15**
–180	**–292**	**93.15**
–160	**–256**	**113.15**
–140	**–220**	**133.15**
–120	**–184**	**153.15**
–100	**–148**	**173.15**
–80	**–112**	**193.15**
–60	**–76**	**213.15**
–40	**–40**	**233.15**
–20	**–4**	**253.15**
–17.77	0	255.372
0	**32**	**273.15**
5	**41**	**278.15**
10	**50**	**283.15**
15	**59**	**288.15**
20	**68**	**293.15**
25	**77**	**298.15**
30	**86**	**303.15**
35	**95**	**308.15**
40	**104**	**313.15**
45	**113**	**318.15**
50	**122**	**323.15**
55	**131**	**328.15**
60	**140**	**333.15**
65	**149**	**338.15**
70	**158**	**343.15**
75	**167**	**348.15**
80	**176**	**353.15**
85	**185**	**358.15**
90	**194**	**363.15**
95	**203**	**368.15**
100	**212**	**373.15**
105	**221**	**378.15**
110	**230**	**383.15**
115	**239**	**378.15**
120	**248**	**393.15**
140	**284**	**413.15**
160	**320**	**433.15**
180	**356**	**453.15**
200	**392**	**473.15**
250	**482**	**523.15**
300	**572**	**573.15**
350	**662**	**623.15**
400	**752**	**673.15**
450	**842**	**723.15**
500	**932**	**773.15**
1 000	**1 832**	**1 273.15**
5 000	**9 032**	**5 273.15**
10 000	**18 032**	**10 273.15**

NOTE: Temperature in kelvins equals temperature in degrees Rankine divided by 1.8 [K = °R/**1.8**].

TABLE 1-28 Light Conversion Factors

(Exact conversions are shown in **boldface** type. Repeating decimals are underlined.)

A. Luminance units. The SI unit of luminance is the candela per square meter (cd/m^2).

	Candelas per square meter (cd/m^2)	Candelas per square foot (cd/ft^2)	Candelas per square inch (cd/in^2)	Apostilbs (asb)	Stilbs (sb)	Lamberts (L)	Footlamberts (fL)
1 candela per square meter =	**1**	**0.092 903 04**	**6.451 6 × 10^{-4}**	π = 3.141 592 65	**0.000 1**	**(0.000 1) π** = 3.141 592 65 × 10^{-4}	0.291 863 51
1 candela per square foot =	10.763 910 4	**1**	**1/144** = 0.006 944 44	33.815 821 8	1.076 391 04 × 10^{-3}	3.381 582 18 × 10^{-3}	**π** = 3.141 592 65
1 candela per square inch =	1 550.003 1	**144**	**1**	4 869.478 4	0.155 000 31	0.486 947 84	452.389 342
1 apostilb =	**1/π** = 0.318 309 89	0.029 571 96	2.053 608 06 × 10^{-4}	**1**	3.183 098 86 × 10^{-5}	**0.000 1**	**0.092 903 04**
1 stilb =	**10 000**	**929.030 4**	**6.451 6**	31 415.926 5	**1**	**π** = 3.141 592 65	2 918.635
1 lambert =	**10 000/π** = 3 183.098 86	295.719 561	2.053 608 06	**10 000**	**1/π** = 0.318 309 89	**1**	**929.030 4**
1 footlambert =	3.426 259 1	**1/π** = 0.318 309 89	2.210 485 32 × 10^{-3}	10.763 910 4	3.426 259 1 × 10^{-4}	1.076 391 03 × 10^{-3}	**1**

NOTE: 1 nit (nt) = 1 candela per square meter (cd/m^2).
1 stilb (sb) = 1 candela per square centimeter (cd/cm^2).

B. Illuminance units. The SI unit of illuminance is the lux (lux).

	Luxes (lx)	Phots (ph)	Footcandles (fc)	Lumens per square inch (lm/in^2)
1 lux =	**1**	**0.000 1**	**0.092 903 04**	**6.451 6 × 10^{-4}**
1 phot =	**10 000**	**1**	**929.030 4**	**6.451 6**
1 footcandle =	10.763 910 4	1.076 391 04 × 10^{-3}	**1**	**1/144** = 0.006 944 44
1 lumen per square inch =	1 550.003 1	0.155 000 31	**144**	**1**

NOTE: 1 lux (lux) = 1 lumen per square meter (lm/m^2).
1 phot (ph) = 1 lumen per square centimeter (lm/cm^2).
1 footcandle (fc) = 1 lumen per square foot (lm/ft^2).

This table contains similar statements relating the meter, yard, foot, inch, mil, and microinch to each other, that is, conversion factors between the non-SI units as well as to and from the SI unit are given. In all, these tables contain over 1700 such statements. Exact conversion factors are indicated in **boldface** type.

Tabulation Groups. To produce tables that can be contained on individual pages of the handbook, units of a given quantity have been arranged in separate subtabulations identified by capital letters. Each such subtabulation represents a group of units related to each other decimally, by magnitude or by usage. Each subtabulation contains the SI unit,* so equivalent values can be found between units that are tabulated in separate tables. For example, to obtain equivalence between pounds per cubic foot and tonnes per cubic meter, we read from the fourth line of Table 1-21B:

1 pound per cubic foot is equal to 16.018 463 4 kilograms per cubic meter

From the first line of Table 1-21A, we find:

1 kilogram per cubic meter is equal to 0.001 metric ton per cubic meter

Hence,

1 pound per cubic foot is equal to 16.018 463 4 kilograms per cubic meter

= 0.016 018 463 4 metric ton per cubic meter

Use of Conversion Factors. Conversion factors are multipliers used to convert a quantity expressed in a particular unit *(given unit)* to the same quantity expressed in another unit *(desired unit)*. To perform such conversions, the *given unit* is found at the left-hand edge of the conversion table, and the *desired unit* is found at the top of the same table. Suppose, for example, the quantity 1000 feet is to be converted to meters. The given unit, foot, is found in the left-hand edge of the third line of Table 1-15B. The desired unit, meter, is found at the top of the first column in that table. The conversion factor (**0.304 8**, exactly) is located to the right of the given unit and below the desired unit. The given quantity, 1000 feet, is multiplied by the conversion factor to obtain the equivalent length in meters, that is, 1000 feet is $1000 \times 0.304\ 8 = 304.8$ meters.

The general rule is: Find the given unit at the left side of the table in which it appears and the desired unit at the top of the same table; note the conversion factor to the right of the given unit and below the desired unit. Multiply the quantity expressed in the given unit by the conversion factor to find the quantity expressed in the desired unit.

Listings of conversion factors (see Refs. 1 and 7) are often arranged as follows:

To convert from	*To*	*Multiply by*
(Given unit)	(Desired unit)	(Conversion factor)

The equivalences listed in the accompanying conversion tables can be cast in this form by placing the given unit (at the left of each table) under "To convert from," the desired units (at the top of the table) under "To," and the conversion factor, found to the right and below these units, under "Multiply by."

Use of Two Tables to Find Conversion Factors. When the given and desired units do not appear in the same table, the conversion factor between them is found in two steps. The *given unit* is selected at the left-hand edge of the table in which it appears, and an *intermediate conversion factor,* applicable

*In Tables 1-17C, 1-17D, 1-17E, and 1-18B, a decimal submultiple of the SI unit (the liter and gram, respectively) is listed because it is most commonly used in conjunction with the other units in the respective tables. The procedure for linking the subtables is unchanged.

TABLE 1-29 U.S. Electrical Units Used Prior to 1969, with SI Equivalents

A. Legal units in the U.S. prior to January 1948	
1 ampere (US-INT)	= 0.999 843 ampere (SI)
1 coulomb (US-INT)	= 0.999 843 coulomb (SI)
1 farad (US-INT)	= 0.999 505 farad (SI)
1 henry (US-INT)	= 1.000 495 henry (SI)
1 joule (US-INT)	= 1.000 182 joule (SI)
1 ohm (US-INT)	= 1.000 495 ohm (SI)
1 volt (US-INT)	= 1.000 338 volt (SI)
1 watt (US-INT)	= 1.000 182 watt (SI)
B. Legal units in the U.S. from January 1948 to January 1969	
1 ampere (US-48)	= 1.000 008 ampere (SI)
1 coulomb (US-48)	= 1.000 008 coulomb (SI)
1 farad (US-48)	= 0.999 505 farad (SI)
1 henry (US-48)	= 1.000 495 henry (SI)
1 joule (US-48)	= 1.000 017 joule (SI)
1 ohm (US-48)	= 1.000 495 ohm (SI)
1 volt (US-48)	= 1.000 008 volt (SI)
1 watt (US-48)	= 1.000 017 watt (SI)

to the SI unit shown at the top of the same table, is recorded. The *desired unit* is then found at the top of another table in which it appears, and another *intermediate conversion factor*, applicable to the SI unit at the left-hand edge of that table, is recorded. The conversion factor between the given and desired units is the product of these two intermediate conversion factors.

For example, it is required to convert 100 cubic feet to the equivalent quantity in cubic centimeters. The given quantity (cubic feet) is found in the fourth line at the left of Table 1-17B. Its intermediate conversion factor with respect to the SI unit is found below the cubic meters to be $2.831\,684\,66 \times 10^{-2}$. The desired quantity (cubic centimeters) is found at the top of the third column in Table 1-17A. Its intermediate conversion factor with respect to the SI unit, found under the cubic centimeters and to the right of the cubic meters, is 1 000 000. The conversion factor between cubic feet and cubic centimeters is the product of these two intermediate conversion factors, that is, 1 cubic foot is equal to $2.831\,684\,66 \times 10^{-2} \times 1\,000\,000 = 28\,316.846\,6$ cubic centimeters. The conversion from 100 cubic feet to cubic centimeters then yields $100 \times 28\,316.846\,6 = 2\,831\,684.66$ cubic centimeters.

Conversion of Electrical Units. Since the electrical units in current use are confined to the International System, conversions to or from non-SI units are fortunately not required in modern practice. Conversions to and from the older cgs units, when required, can be performed using the conversions shown in Table 1-9. Slight differences from the SI units occur in the electrical units legally recognized in the United States prior to 1969. These differences involve amounts smaller than that customarily significant in engineering; they are listed in Table 1-29.

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