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Chemical Engineering, Chemistry, and Materials Science

INTERNATIONAL SYSTEM OF UNITS (SI)

1 SI base units

Table 1 gives the seven base quantities, assumed to be mutually independent, on which the SI is founded; and the names and symbols of their respective units, called ``SI base units.'' Definitions of the SI base units are given in Appendix A. The kelvin and its symbol K are also used to express the value of a temperature interval or a temperature difference.

Table 1. SI base units

Base quantity	SI base unit	
	Name	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

2 SI derived units

Derived units are expressed algebraically in terms of base units or other derived units (including the radian and steradian which are the two supplementary units – see Sec. 3). The symbols for derived units are obtained by means of the mathematical operations of multiplication and division. For example, the derived unit for the derived quantity molar mass (mass divided by amount of substance) is the kilogram per mole, symbol kg/mol. Additional examples of derived units expressed in terms of SI base units are given in Table 2.

Table 2. Examples of SI derived units expressed in terms of SI base units

Derived quantity	SI derived unit	
	Name	Symbol
area	square meter	m^2
volume	cubic meter	m^3
speed, velocity	meter per second	m/s
acceleration	meter per second squared	m/s^2
wave number	reciprocal meter	m^{-1}
mass density (density)	kilogram per cubic meter	kg/m^3
specific volume	cubic meter per kilogram	m^3/kg
current density	ampere per square meter	A/m^2
magnetic field strength	ampere per meter	A/m
amount-of-substance concentration (concentration)	mole per cubic meter	mol/m^3
luminance	candela per square meter	cd/m^2

2.1 SI derived units with special names and symbols

Certain SI derived units have special names and symbols; these are given in Tables 3a and 3b. As discussed in Sec. 3, the radian and steradian, which are the two supplementary units, are included in Table 3a.

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Table 3a. SI derived units with special names and symbols, including the radian and steradian

Derived quantity	SI derived unit			
	Special name	Special symbol	Expression in terms of other SI units	Expression in terms of SI base units
plane angle	radian	rad		$m \cdot m^{-1} = 1$
solid angle	steradian	sr		$m^2 \cdot m^{-2} = 1$
frequency	hertz	Hz		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	$m^2 \cdot kg \cdot s^{-3}$
electric charge, quantity of electricity	coulomb	C		$s \cdot A$
electric potential, potential difference, electromotive force	volt	V	W/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
capacitance	farad	F	C/V	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
electric resistance	ohm	Ω	V/A	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
electric 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	$kg \cdot s^{-2} \cdot A^{-1}$
inductance	henry	H	Wb/A	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
Celsius temperature[(a)]	degree Celsius	°C		K
luminous flux	lumen	lm	$cd \cdot sr$	$cd \cdot sr$[(b)]
illuminance	lux	lx	lm/m^2	$m^{-2} \cdot cd \cdot sr$[(b)]

[(a)] See Sec. 2.1.1.
[(b)] The steradian (sr) is not an SI base unit. However, in photometry the steradian (sr) is maintained in expressions for units (see Sec. 3).

Table 3b. SI derived units with special names and symbols admitted for reasons of safeguarding human health[(a)]

Derived quantity	SI derived unit			
	Special name	Special symbol	Expression in terms of other SI units	Expression in terms of SI base units
activity (of a radionuclide)	becquerel	Bq		s^{-1}
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$m^2 \cdot s^{-2}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent, equivalent dose	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$

[(a)] The derived quantities to be expressed in the gray and the sievert have been revised in accordance with the recommendations of the International Commission on Radiation Units and Measurements (ICRU).

2.1.1 Degree Celsius In addition to the quantity thermodynamic temperature (symbol T), expressed in the unit kelvin, use is also made of the quantity Celsius temperature (symbol t) defined by the equation

$$t = T - T_0 \ ,$$

where $T_0 = 273.15$ K by definition. To express Celsius temperature, the unit degree Celsius, symbol °C, which is equal in magnitude to the unit kelvin, is used; in this case, ``degree Celsius'' is a special name used in place of ``kelvin.'' An interval or difference of Celsius temperature can, however, be expressed in the unit kelvin as well as in the unit degree Celsius. (Note that the thermodynamic temperature T_0 is exactly 0.01 K below the thermodynamic temperature of the triple point of water.)

INTERNATIONAL SYSTEM OF UNITS (SI) (continued)

2.2 Use of SI derived units with special names and symbols

Examples of SI derived units that can be expressed with the aid of SI derived units having special names and symbols (including the radian and steradian) are given in Table 4.

Table 4. Examples of SI derived units expressed with the aid of SI derived units having special names and symbols

	SI derived unit		
Derived quantity	Name	Symbol	Expression in terms of SI base units
angular velocity	radian per second	rad/s	$m \cdot m^{-1} \cdot s^{-1} = s^{-1}$
angular acceleration	radian per second squared	rad/s^2	$m \cdot m^{-1} \cdot s^{-2} = s^{-2}$
dynamic viscosity	pascal second	$Pa \cdot s$	$m^{-1} \cdot kg \cdot s^{-1}$
moment of force	newton meter	$N \cdot m$	$m^2 \cdot kg \cdot s^{-2}$
surface tension	newton per meter	N/m	$kg \cdot s^{-2}$
heat flux density, irradiance	watt per square meter	W/m^2	$kg \cdot s^{-3}$
radiant intensity	watt per steradian	W/sr	$m^2 \cdot kg \cdot s^{-3} \cdot sr^{-1}$ [a]
radiance	watt per square meter steradian	$W/(m^2 \cdot sr)$	$kg \cdot s^{-3} \cdot sr^{-1}$ [a]
heat capacity, entropy	joule per kelvin	J/K	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1}$
specific heat capacity, specific entropy	joule per kilogram kelvin	$J/(kg \cdot K)$	$m^2 \cdot s^{-2} \cdot K^{-1}$
specific energy	joule per kilogram	J/kg	$m^2 \cdot s^{-2}$
thermal conductivity	watt per meter kelvin	$W/(m \cdot K)$	$m \cdot kg \cdot s^{-3} \cdot K^{-1}$
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	$m^{-3} \cdot kg^{-1} \cdot s^4 \cdot A^2$
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	$J/(mol \cdot K)$	$m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$
exposure (x and γ rays)	coulomb per kilogram	C/kg	$kg^{-1} \cdot s \cdot A$
absorbed dose rate	gray per second	Gy/s	$m^2 \cdot s^{-3}$

[a] The steradian (sr) is not an SI base unit. However, in radiometry the steradian (sr) is maintained in expressions for units (see Sec. 3).

The advantages of using the special names and symbols of SI derived units are apparent in Table 4. Consider, for example, the quantity molar entropy: the unit $J/(mol \cdot K)$ is obviously more easily understood than its SI base-unit equivalent, $m^2 \cdot kg \cdot s^{-2} \cdot K^{-1} \cdot mol^{-1}$. Nevertheless, it should always be recognized that the special names and symbols exist for convenience; either the form in which special names or symbols are used for certain combinations of units or the form in which they are not used is correct. For example, because of the descriptive value implicit in the compound-unit form, communication is sometimes facilitated if magnetic flux (see Table 3a) is expressed in terms of the volt second ($V \cdot s$) instead of the weber (Wb).

Tables 3a, 3b, and 4 also show that the values of several different quantities are expressed in the same SI unit. For example, the joule per kelvin (J/K) is the SI unit for heat capacity as well as for entropy. Thus the name of the unit is not sufficient to define the quantity measured.

A derived unit can often be expressed in several different ways through the use of base units and derived units with special names. In practice, with certain quantities, preference is given to using certain units with special names, or combinations of units, to facilitate the distinction between quantities whose values have identical expressions in terms of SI base units. For example, the SI unit of frequency is specified as the hertz (Hz) rather than the reciprocal second (s^{-1}), and the SI unit of moment of force is specified as the newton meter ($N \cdot m$) rather than the joule (J).

INTERNATIONAL SYSTEM OF UNITS (SI) (continued)

Similarly, in the field of ionizing radiation, the SI unit of activity is designated as the becquerel (Bq) rather than the reciprocal second (s^{-1}), and the SI units of absorbed dose and dose equivalent are designated as the gray (Gy) and the sievert (Sv), respectively, rather than the joule per kilogram (J/kg).

3 SI supplementary units

As previously stated, there are two units in this class: the radian, symbol rad, the SI unit of the quantity plane angle; and the steradian, symbol sr, the SI unit of the quantity solid angle. Definitions of these units are given in Appendix A.

The SI supplementary units are now interpreted as so-called dimensionless derived units for which the CGPM allows the freedom of using or not using them in expressions for SI derived units.[3] Thus the radian and steradian are not given in a separate table but have been included in Table 3a together with other derived units with special names and symbols (seeSec.2.1). This interpretation of the supplementary units implies that plane angle and solid angle are considered derived quantities of dimension one (so-called dimensionless quantities), each of which has the which has the unit one, symbol 1, as its coherent SI unit. However, in practice, when one expresses the values of derived quantities involving plane angle or solid angle, it often aids understanding if the special names (or symbols) ``radian'' (rad) or ``steradian'' (sr) are used in place of the number 1. For example, although values of the derived quantity angular velocity (plane angle divided by time) may be expressed in the unit s^{-1}, such values are usually expressed in the unit rad/s.

Because the radian and steradian are now viewed as so-called dimensionless derived units, the Consultative Committee for Units (CCU, *Comité Consultatif des Unités*) of the CIPM as result of a 1993 request it received from ISO/TC12, recommended to the CIPM that it request the CGPM to abolish the class of supplementary units as a separate class in the SI. The CIPM accepted the CCU recommendation, and if the abolishment is approved by the CGPM as is likely (the question will be on the agenda of the 20th CGPM, October 1995), the SI will consist of only two classes of units: base units and derived units, with the radian and steradian subsumed into the class of derived units of the SI. (The option of using or not using them in expressions for SI derived units, as is convenient, would remain unchanged.)

4 Decimal multiples and submultiples of SI units: SI prefixes

Table 5 gives the SI prefixes that are used to form decimal multiples and submultiples of SI units. They allow very large or very small numerical values to be avoided. A prefix attaches directly to the name of a unit, and a prefix symbol attaches directly to the symbol for a unit. For example, one kilometer, symbol 1 km, is equal to one thousand meters, symbol 1000 m or 10^3 m. When prefixes are attached to SI units, the units so formed are called ``multiples and submultiples of SI units'' in order to distinguish them from the coherent system of SI units.

Note: Alternative definitions of the SI prefixes and their symbols are not permitted. For example, it is unacceptable to use kilo (k) to represent $2^{10} = 1024$, mega (M) to represent $2^{20} = 1\ 048\ 576$, or giga (G) to represent $2^{30} = 1\ 073\ 741\ 824$.

[3] This interpretation was given in 1980 by the CIPM . It was deemed necessary because Resolution 12 of the 11th CGPM, which established the SI in 1960 , did not specify the nature of the supplementary units. The interpretation is based on two principal considerations: that plane angle is generally expressed as the ratio of two lengths and solid angle as the ratio of an area and the square of a length, and are thus quantities of dimension one (so-called dimensionless quantities); and that treating the radian and steradian as SI base units – a possibility not disallowed by Resolution 12 – could compromise the internal coherence of the SI based on only seven base units. (See ISO 31-0 for a discussion of the concept of dimension.)

INTERNATIONAL SYSTEM OF UNITS (SI) (continued)

Table 5. SI prefixes

Factor	Prefix	Symbol	Factor	Prefix	Symbol
$10^{24} = (10^3)^8$	yotta	Y	10^{-1}	deci	d
$10^{21} = (10^3)^7$	zetta	Z	10^{-2}	centi	c
$10^{18} = (10^3)^6$	exa	E	$10^{-3} = (10^3)^{-1}$	milli	m
$10^{15} = (10^3)^5$	peta	P	$10^{-6} = (10^3)^{-2}$	micro	μ
$10^{12} = (10^3)^4$	tera	T	$10^{-9} = (10^3)^{-3}$	nano	n
$10^{9} = (10^3)^3$	giga	G	$10^{-12} = (10^3)^{-4}$	pico	p
$10^{6} = (10^3)^2$	mega	M	$10^{-15} = (10^3)^{-5}$	femto	f
$10^{3} = (10^3)^1$	kilo	k	$10^{-18} = (10^3)^{-6}$	atto	a
10^{2}	hecto	h	$10^{-21} = (10^3)^{-7}$	zepto	z
10^{1}	deka	da	$10^{-24} = (10^3)^{-8}$	yocto	y

5 Units Outside the SI

Units that are outside the SI may be divided into three categories:

- those units that are accepted for use with the SI;
- those units that are temporarily accepted for use with the SI; and
- those units that are not accepted for use with the SI and thus must strictly be avoided.

5.1 Units accepted for use with the SI

The following sections discuss in detail the units that are acceptable for use with the SI.

5.1.1 Hour, degree, liter, and the like

Certain units that are not part of the SI are essential and used so widely that they are accepted by the CIPM for use with the SI. These units are given in Table 6. The combination of units of this table with SI units to form derived units should be restricted to special cases in order not to lose the advantages of the coherence of SI units.

Additionally, it is recognized that it may be necessary on occasion to use time-related units other than those given in Table 6; in particular, circumstances may require that intervals of time be expressed in weeks, months, or years. In such cases, if a standardized symbol for the unit is not available, the name of the unit should be written out in full.

Table 6. Units accepted for use with the SI

Name		Symbol	Value in SI units
minute	time	min	1 min = 60 s
hour	time	h	1 h = 60 min = 3600 s
day	time	d	1 d = 24 h = 86 400 s
degree	plane angle	°	1° = (π/180) rad
minute	plane angle	'	1' = (1/60)°=(π/10 800) rad
second	plane angle	"	1" = (1/60)' =(π/648 000) rad
liter		l, L[b]	1 L = 1 dm^3 = 10^{-3} m^3
metric ton[c]		t	1 t = 10^3 kg

[b] The alternative symbol for the liter, L, was adopted by the CGPM in order to avoid the risk of confusion between the letter l and the number 1 . Thus, although both l and L are internationally accepted symbols for the liter, to avoid this risk the symbol to be used in the United States is L . The script letter ℓ is not an approved symbol for the liter.

[c] This is the name to be used for this unit in the United States; it is also used in some other English-speaking countries. However, ``tonne'' is used in many countries.

INTERNATIONAL SYSTEM OF UNITS (SI) (continued)

5.1.2 Neper, bel, shannon, and the like

There are a few highly specialized units not listed in Table 6 that are given by the International Organization for Standardization (ISO) or the International Electrotechnical Commission (IEC) and which are also acceptable for use with the SI. They include the neper (Np), bel (B), octave, phon, and sone, and units used in information technology, including the baud (Bd), bit (bit), erlang (E), hartley (Hart), and shannon (Sh).[4] It is the position of NIST that the only such additional units that may be used with the SI are those given in either the International Standards on quantities and units of ISO or of IEC .

5.1.3 Electronvolt and unified atomic mass unit

The CIPM also finds it necessary to accept for use with the SI the two units given in Table 7. These units are used in specialized fields; their values in SI units must be obtained from experiment and, therefore, are not known exactly.

Note: In some fields the unified atomic mass unit is called the dalton, symbol Da; however, this name and symbol are not accepted by the CGPM, CIPM, ISO, or IEC for use with the SI. Similarly, AMU is not an acceptable unit symbol for the unified atomic mass unit. The only allowed name is ``unified atomic mass unit'' and the only allowed symbol is u.

Table 7. Units accepted for use with the SI whose values in SI units are obtained experimentally

Name	Symbol	Definition
electronvolt	eV	(a)
unified atomic mass unit	u	(b)

(a) The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 V in vacuum; 1 eV = 1.602 177 33$\times 10^{-19}$ J with a combined standard uncertainty of 0.000 000 49$\times 10^{-19}$ J .

(b) The unified atomic mass unit is equal to 1/12 of the mass of an atom of the nuclide ^{12}C; 1 u = 1.660 540 2$\times$ 10^{-27} kg with a combined standard uncertainty of 0.000 001 0$\times 10^{-27}$ kg .

5.1.4 Natural and atomic units

In some cases, particularly in basic science, the values of quantities are expressed in terms of fundamental constants of nature or so-called natural units.The use of these units with the SI is permissible when it is necessary for the most effective communication of information. In such cases, the specific natural units that are used must be identified. This requirement applies even to the system of units customarily called ``atomicunits'' used in theoretical atomic physics and chemistry, inasmuch as there are several different systems that have the appellation ``atomic units." Examples of physical quantities used as natural units are given in Table 8.

NIST also takes the position that while theoretical results intended primarily for other theorists may be left in natural units, if they are also intended for experimentalists, they must also be given in acceptable units.

[4] The symbol in parentheses following the name of the unit is its internationally accepted unit symbol, but the octave, phon, and sone have no such unit symbols. For additional information on the neper and bel, see Sec. 0.5 of ISO 31-2.
The question of the byte (B) is under international consideration.

INTERNATIONAL SYSTEM OF UNITS (SI) (continued)

Table 8. Examples of physical quantities sometimes used as natural units

Kind of quantity	Physical quantity used as a unit	Symbol
action	Planck constant divided by 2π	$\hbar$
electric charge	elementary charge	e
energy	Hartree energy	E_h
length	Bohr radius	a_0
length	Compton wavelength (electron)	λ_C
magnetic flux	magnetic flux quantum	Φ_0
magnetic moment	Bohr magneton	μ_B
magnetic moment	nuclear magneton	μ_N
mass	electron rest mass	m_e
mass	proton rest mass	m_p
speed	speed of electromagnetic waves in vacuum	c

5.2 Units temporarily accepted for use with the SI

Because of existing practice in certain fields or countries, in 1978 the CIPM considered that it was permissible for the units given in Table 9 to continue to be used with the SI until the CIPM considers that their use is no longer necessary. However, these units must not be introduced where they are not presently used. Further, NIST strongly discourages the continued use of these units except for the nautical mile, knot, are, and hectare; and except for the curie, roentgen, rad, and rem until the year 2000 (the cessation date suggested by the Committee for Ineragency Radiation Research and Policy Coordination or CIRRPC, a United States Government interagency group).[5]

Table 9. Units temporarily accepted for use with the SI[(a)]

Name	Symbol	Value in SI units
nautical mile		1 nautical mile = 1852 m
knot		1 nautical mile per hour = (1852/3600) m/s
ångström	Å	1 Å = 0.1 nm = 10^{-10}m
are[(b)]	a	1 a = 1 dam^2 = 10^2 m^2
hectare[(b)]	ha	1 ha = 1 hm^2 = 10^4 m^2
barn	b	1 b = 100 fm^2 = 10^{-28} m^2
bar	bar	1 bar=0.1 MPa=100 kPa=1000 hPa=10^5 Pa
gal	Gal	1 Gal = 1 cm/s^2 = 10^{-2} m/s^2
curie	Ci	1 Ci = 3.7×10^{10} Bq
roentgen	R	1 R = 2.58×10^{-4} C/kg
rad	rad[(c)]	1 rad = 1 cGy = 10^{-2} Gy
rem	rem	1 rem = 1 cSv = 10^{-2} Sv

[(a)] See Sec. 5.2 regarding the continued use of these units.
[(b)] This unit and its symbol are used to express agrarian areas.
[(c)] When there is risk of confusion with the symbol for the radian, rd may be used as the symbol for rad.

[5] In 1993 the CCU (see Sec. 3) was requested by ISO/TC 12 to consider asking the CIPM to deprecate the use of the units of Table 9 except for the nautical mile and knot, and possibly the are and hectare. The CCU discussed this request at its February 1995 meeting.

INTERNATIONAL SYSTEM OF UNITS (SI) (continued)

Appendix A. Definitions of the SI Base Units and the Radian and Steradian

A.1 Introduction

The following definitions of the SI base units are taken from NIST SP 330; the definitions of the SI supplementary units, the radian and steradian, which are now interpreted as SI derived units (see Sec. 3), are those generally accepted and are the same as those given in ANSI/IEEE Std 268-1992. SI derived units are uniquely defined only in terms of SI base units; for example, $1\ \mathrm{V} = 1\ \mathrm{m}^2 \cdot \mathrm{kg} \cdot \mathrm{s}^{-3} \cdot \mathrm{A}^{-1}$.

A.2 Meter (17th CGPM, 1983)

The meter is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 *of a second.*

A.3 Kilogram (3d CGPM, 1901)

The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

A.4 Second (13th CGPM, 1967)

The second is 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 *atom.*

A.5 Ampere (9th CGPM, 1948)

The ampere is that constant current which, 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.*

A.6 Kelvin (13th CGPM, 1967)

The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 *of the thermodynamic temperature of the triple point of water.*

A.7 Mole (14th CGPM, 1971)

1. *The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in* 0.012 *kilogram of carbon* 12.

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

In the definition of the mole, it is understood that unbound atoms of carbon 12, at rest and in their ground state, are referred to.

Note that this definition specifies at the same time the nature of the quantity whose unit is the mole.

A.8 Candela (16th CGPM, 1979)

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

A.9 Radian

The radian is the plane angle between two radii of a circle that cut off on the circumference an arc equal in length to the radius.

A.10 Steradian

The steradian is the solid angle that, 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 of length equal to the radius of the sphere.

From *CRC Handbook of Chemistry and Physics,* 83rd ed., Lide, D., Ed., CRC Press, Boca Raton, FL, 2002, pp. **1**-25 to **1**-32.

CONVERSION FACTORS

The following table gives conversion factors from various units of measure to SI units. It is reproduced from NIST Special Publication 811, *Guide for the Use of the International System of Units (SI)*. The table gives the factor by which a quantity expressed in a non-SI unit should be multiplied in order to calculate its value in the SI. The SI values are expressed in terms of the base, supplementary, and derived units of SI in order to provide a coherent presentation of the conversion factors and facilitate computations (see the table "International System of Units" in this Section). If desired, powers of ten can be avoided by using SI Prefixes and shifting the decimal point if necessary.

Conversion from a non-SI unit to a different non-SI unit may be carried out by using this table in two stages, e.g.,

$$1\ \text{cal}_{th} = 4.184\ \text{J}$$
$$1\ \text{Btu}_{IT} = 1.055056\ \text{E+03 J}$$

Thus,

$$1\ \text{Btu}_{IT} = (1.055056\ \text{E+03} \div 4.184)\ \text{cal}_{th} = 252.164\ \text{cal}_{th}$$

Conversion factors are presented for ready adaptation to computer readout and electronic data transmission. The factors are written as a number equal to or greater than one and less than ten with six or fewer decimal places. This number is followed by the letter E (for exponent), a plus or a minus sign, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example:

$$3.523\ 907\ \text{E-02 is}\ 3.523\ 907 \times 10^{-2}$$

or

$$0.035\ 239\ 07$$

Similarly:

$$3.386\ 389\ \text{E+03 is}\ 3.386\ 389 \times 10^{3}$$

or

$$3\ 386.389$$

A factor in boldface is exact; i.e., all subsequent digits are zero. All other conversion factors have been rounded to the figures given in accordance with accepted practice. Where less than six digits after the decimal point are shown, more precision is not warranted.

It is often desirable to round a number obtained from a conversion of units in order to retain information on the precision of the value. The following rounding rules may be followed:

(1) If the digits to be discarded begin with a digit less than 5, the digit preceding the first discarded digit is not changed.

Example: 6.974 951 5 rounded to 3 digits is 6.97

(2) If the digits to be discarded begin with a digit greater than 5, the digit preceding the first discarded digit is increased by one.

Example: 6.974 951 5 rounded to 4 digits is 6.975

(3) If the digits to be discarded begin with a 5 and at least one of the following digits is greater than 0, the digit preceding the 5 is increased by 1.

Example: 6.974 851 rounded to 5 digits is 6.974 9

(4) If the digits to be discarded begin with a 5 and all of the following digits are 0, the digit preceding the 5 is unchanged if it is even and increased by one if it is odd. (Note that this means that the final digit is always even.)

Examples: 6.974 951 5 rounded to 7 digits is 6.974 952
6.974 950 5 rounded to 7 digits is 6.974 950

REFERENCE

Taylor, B. N., *Guide for the Use of the International System of Units (SI)*, NIST Special Publication 811, 1995 Edition, Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402, 1995.

Factors in **boldface** are exact

To convert from	to	Multiply by	
abampere	ampere (A)	**1.0**	**E+01**
abcoulomb	coulomb (C)	**1.0**	**E+01**
abfarad	farad (F)	**1.0**	**E+09**
abhenry	henry (H)	**1.0**	**E−09**
abmho	siemens (S)	**1.0**	**E+09**
abohm	ohm (Ω)	**1.0**	**E−09**
abvolt	volt (V)	**1.0**	**E−08**
acceleration of free fall, standard (g_n)	meter per second squared (m/s^2)	**9.806 65**	**E+00**
acre (based on U.S. survey foot)[9]	square meter (m^2)	4.046 873	E+03
acre foot (based on U.S. survey foot)[9]	cubic meter (m^3)	1.233 489	E+03
ampere hour (A · h)	coulomb (C)	**3.6**	**E+03**
ångström (Å)	meter (m)	**1.0**	**E−10**
ångström (Å)	nanometer (nm)	**1.0**	**E−01**
are (a)	square meter (m^2)	**1.0**	**E+02**
astronomical unit (AU)	meter (m)	1.495 979	E+11
atmosphere, standard (atm)	pascal (Pa)	**1.013 25**	**E+05**
atmosphere, standard (atm)	kilopascal (kPa)	**1.013 25**	**E+02**
atmosphere, technical (at)[10]	pascal (Pa)	**9.806 65**	**E+04**
atmosphere, technical (at)[10]	kilopascal (kPa)	**9.806 65**	**E+01**
bar (bar)	pascal (Pa)	**1.0**	**E+05**
bar (bar)	kilopascal (kPa)	**1.0**	**E+02**
barn (b)	square meter (m^2)	**1.0**	**E−28**
barrel [for petroleum, 42 gallons (U.S.)](bbl)	cubic meter (m^3)	1.589 873	E−01
barrel [for petroleum, 42 gallons (U.S.)](bbl)	liter (L)	1.589 873	E+02
biot (Bi)	ampere (A)	**1.0**	**E+01**
British thermal unit$_{IT}$ (Btu$_{IT}$)[11]	joule (J)	1.055 056	E+03
British thermal unit$_{th}$ (Btu$_{th}$)[11]	joule (J)	1.054 350	E+03
British thermal unit (mean) (Btu)	joule (J)	1.055 87	E+03
British thermal unit (39 °F) (Btu)	joule (J)	1.059 67	E+03
British thermal unit (59 °F) (Btu)	joule (J)	1.054 80	E+03
British thermal unit (60 °F) (Btu)	joule (J)	1.054 68	E+03
British thermal unit$_{IT}$ foot per hour square foot degree Fahrenheit [$Btu_{IT} \cdot ft/(h \cdot ft^2 \cdot °F)$]	watt per meter kelvin [$W/(m \cdot K)$]	1.730 735	E+00
British thermal unit$_{th}$ foot per hour square foot degree Fahrenheit [$Btu_{th} \cdot ft/(h \cdot ft^2 \cdot °F)$]	watt per meter kelvin [$W/(m \cdot K)$]	1.729 577	E+00
British thermal unit$_{IT}$ inch per hour square foot degree Fahrenheit [$Btu_{IT} \cdot in/(h \cdot ft^2 \cdot °F)$]	watt per meter kelvin [$W/(m \cdot K)$]	1.442 279	E−01
British thermal unit$_{th}$ inch per hour square foot degree Fahrenheit [$Btu_{th} \cdot in/(h \cdot ft^2 \cdot °F)$]	watt per meter kelvin [$W/(m \cdot K)$]	1.441 314	E−01
British thermal unit$_{IT}$ inch per second square foot degree Fahrenheit [$Btu_{IT} \cdot in/(s \cdot ft^2 \cdot °F)$]	watt per meter kelvin [$W/(m \cdot K)$]	5.192 204	E+02

[9] The U.S. survey foot equals (1200/3937) m. 1 international foot = 0.999998 survey foot.
[10] One technical atmosphere equals one kilogram-force per square centimeter (1 at = 1 kgf/cm^2).
[11] The Fifth International Conference on the Properties of Steam (London, July 1956) defined the International Table calorie as 4.1868 J. Therefore the exact conversion factor for the International Table Btu is 1.055 055 852 62 kJ. Note that the notation for International Table used in this listing is subscript ''IT''. Similarily, the notation for thermochemical is subscript ''th.'' Further, the thermochemical Btu, Btu$_{th}$, is based on the thermochemical calorie, cal$_{th}$, where cal$_{th}$ = 4.184 J exactly.

To convert from	to	Multiply by	
British thermal unit$_{th}$ inch per second square foot degree Fahrenheit [Btu$_{th}$ · in/(s · ft^2 · °F)]	watt per meter kelvin [W/(m · K)]	5.188 732	E+02
British thermal unit$_{IT}$ per cubic foot (Btu$_{IT}$/ft^3)	joule per cubic meter (J/m^3)	3.725 895	E+04
British thermal unit$_{th}$ per cubic foot (Btu$_{th}$/ft^3)	joule per cubic meter (J/m^3)	3.723 403	E+04
British thermal unit$_{IT}$ per degree Fahrenheit (Btu$_{IT}$/°F)	joule per kelvin (J/k)	1.899 101	E+03
British thermal unit$_{th}$ per degree Fahrenheit (Btu$_{th}$/°F)	joule per kelvin (J/k)	1.897 830	E+03
British thermal unit$_{IT}$ per degree Rankine (Btu$_{IT}$/°R)	joule per kelvin (J/k)	1.899 101	E+03
British thermal unit$_{th}$ per degree Rankine (Btu$_{th}$/°R)	joule per kelvin (J/k)	1.897 830	E+03
British thermal unit$_{IT}$ per hour (Btu$_{IT}$/h)	watt (W)	2.930 711	E−01
British thermal unit$_{th}$ per hour (Btu$_{th}$/h)	watt (W)	2.928 751	E−01
British thermal unit$_{IT}$ per hour square foot degree Fahrenheit [Btu$_{IT}$/(h · ft^2 · °F)]	watt per square meter kelvin [W/(m^2 · K)]	5.678 263	E+00
British thermal unit$_{th}$ per hour square foot degree Fahrenheit [Btu$_{th}$/(h · ft^2 · °F)]	watt per square meter kelvin [W/(m^2 · K)]	5.674 466	E+00
British thermal unit$_{th}$ per minute (Btu$_{th}$/min)	watt (W)	1.757 250	E+01
British thermal unit$_{IT}$ per pound (Btu$_{IT}$/lb)	joule per kilogram (J/kg)	**2.326**	**E+03**
British thermal unit$_{th}$ per pound (Btu$_{th}$/lb)	joule per kilogram (J/kg)	2.324 444	E+03
British thermal unit$_{IT}$ per pound degree Fahrenheit [Btu$_{IT}$/(lb · °F)]	joule per kilogram kelvin (J/(kg · K)]	**4.1868**	**E+03**
British thermal unit$_{th}$ per pound degree Fahrenheit [Btu$_{th}$/(lb · °F)]	joule per kilogram kelvin [J/(kg · K)]	**4.184**	**E+03**
British thermal unit$_{IT}$ per pound degree Rankine [Btu$_{IT}$/(lb · °R)]	joule per kilogram kelvin [J/(kg · K)]	**4.1868**	**E+03**
British thermal unit$_{th}$ per pound degree Rankine [Btu$_{th}$/(lb · °R)]	joule per kilogram kelvin [J/(kg · K)]	**4.184**	**E+03**
British thermal unit$_{IT}$ per second (Btu$_{IT}$/s)	watt (W)	1.055 056	E+03
British thermal unit$_{th}$ per second (Btu$_{th}$/s)	watt (W)	1.054 350	E+03
British thermal unit$_{IT}$ per second square foot degree Fahrenheit [Btu$_{IT}$/(s · ft^2 · °F)]	watt per square meter kelvin [W/(m^2 · K)]	2.044 175	E+04
British thermal unit$_{th}$ per second square foot degree Fahrenheit [Btu$_{th}$/(s · ft^2 · °F)]	watt per square meter kelvin [W/(m^2 · K)]	2.042 808	E+04
British thermal unit$_{IT}$ per square foot (Btu$_{IT}$/ft^2)	joule per square meter (J/m^2)	1.135 653	E+04
British thermal unit$_{th}$ per square foot (Btu$_{th}$/ft^2)	joule per square meter (J/m^2)	1.134 893	E+04
British thermal unit$_{IT}$ per square foot hour [(Btu$_{IT}$/(ft^2 · h)]	watt per square meter (W/m^2)	3.154 591	E+00
British thermal unit$_{th}$ per square foot hour [Btu$_{th}$/(ft^2 · h)]	watt per square meter (W/m^2)	3.152 481	E+00
British thermal unit$_{th}$ per square foot minute [Btu$_{th}$/(ft^2 · min)]	watt per square meter (W/m^2)	1.891 489	E+02
British thermal unit$_{IT}$ per square foot second [(Btu$_{IT}$/(ft^2 · s)]	watt per square meter (W/m^2)	1.135 653	E+04
British thermal unit$_{th}$ per square foot second [Btu$_{th}$/(ft^2 · s)]	watt per square meter (W/m^2)	1.134 893	E+04
British thermal unit$_{th}$ per square inch second [Btu$_{th}$/(in^2 · s)]	watt per square meter (W/m^2)	1.634 246	E+06

To convert from	to	Multiply by	
bushel (U.S.) (bu)	cubic meter (m^3)	3.523 907	E−02
bushel (U.S.) (bu)	liter (L)	3.523 907	E+01
calorie$_{IT}$ (cal$_{IT}$)[11]	joule (J)	**4.1868**	**E+00**
calorie$_{th}$ (cal$_{th}$)[11]	joule (J)	**4.184**	**E+00**
calorie (cal) (mean)	joule (J)	4.190 02	E+00
calorie (15 °C) (cal$_{15}$)	joule (J)	4.185 80	E+00
calorie (20 °C) (cal$_{20}$)	joule (J)	4.181 90	E+00
calorie$_{IT}$, kilogram (nutrition)[12]	joule (J)	**4.1868**	**E+03**
calorie$_{th}$, kilogram (nutrition)[12]	joule (J)	**4.184**	**E+03**
calorie (mean), kilogram (nutrition)[12]	joule (J)	4.190 02	E+03
calorie$_{th}$ per centimeter second degree Celsius [cal$_{th}$/(cm · s · °C)]	watt per meter kelvin [W/(m · K)]	**4.184**	**E+02**
calorie$_{IT}$ per gram (cal$_{IT}$/g)	joule per kilogram (J/kg)	**4.1868**	**E+03**
calorie$_{th}$ per gram (cal$_{th}$/g)	joule per kilogram (J/kg)	**4.184**	**E+03**
calorie$_{IT}$ per gram degree Celsius [cal$_{IT}$/(g · °C)]	joule per kilogram kelvin [J/(kg · K)]	**4.1868**	**E+03**
calorie$_{th}$ per gram degree Celsius [cal$_{th}$/(g · °C)]	joule per kilogram kelvin [J/(kg · K)]	**4.184**	**E+03**
calorie$_{IT}$ per gram kelvin [cal$_{IT}$/(g · K)]	joule per kilogram kelvin [J/(kg · K)]	**4.1868**	**E+03**
calorie$_{th}$ per gram kelvin [cal$_{th}$/(g · K)]	joule per kilogram kelvin [J/(kg · K)]	**4.184**	**E+03**
calorie$_{th}$ per minute (cal$_{th}$/min)	watt (W)	6.973 333	E−02
calorie$_{th}$ per second (cal$_{th}$/s)	watt (W)	**4.184**	**E+00**
calorie$_{th}$ per square centimeter (cal$_{th}$/cm^2)	joule per square meter (J/m^2)	**4.184**	**E+04**
calorie$_{th}$ per square centimeter minute [cal$_{th}$/(cm^2 · min)]	watt per square meter (W/m^2)	6.973 333	E+02
calorie$_{th}$ per square centimeter second [cal$_{th}$/(cm^2 · s)]	watt per square meter (W/m^2)	**4.184**	**E+04**
candela per square inch (cd/in^2)	candela per square meter (cd/m^2)	1.550 003	E+03
carat, metric	kilogram (kg)	**2.0**	**E−04**
carat, metric	gram (g)	**2.0**	**E−01**
centimeter of mercury (0 °C)[13]	pascal (Pa)	1.333 22	E+03
centimeter of mercury (0 °C)[13]	kilopascal (kPa)	1.333 22	E+00
centimeter of mercury, conventional (cmHg)[13]	pascal (Pa)	1.333 224	E+03
centimeter of mercury, conventional (cmHg)[13]	kilopascal (kPa)	1.333 224	E+00
centimeter of water (4 °C)[13]	pascal (Pa)	9.806 38	E+01
centimeter of water, conventional (cmH_2O)[13]	pascal (Pa)	**9.806 65**	**E+01**
centipoise (cP)	pascal second (Pa · s)	**1.0**	**E−03**
centistokes (cSt)	meter squared per second (m^2/s)	**1.0**	**E−06**
chain (based on U.S. survey foot) (ch)[9]	meter (m)	2.011 684	E+01
circular mil	square meter (m^2)	5.067 075	E−10
circular mil	square millimeter (mm^2)	5.067 075	E−04
clo	square meter kelvin per watt (m^2 · K/W)	1.55	E−01
cord (128 ft^3)	cubic meter (m^3)	3.624 556	E+00
cubic foot (ft^3)	cubic meter (m^3)	2.831 685	E−02
cubic foot per minute (ft^3/min)	cubic meter per second (m^3/s)	4.719 474	E−04
cubic foot per minute (ft^3/min)	liter per second (L/s)	4.719 474	E−01
cubic foot per second (ft^3/s)	cubic meter per second (m^3/s)	2.831 685	E−02

[12] The kilogram calorie or ''large calorie'' is an obsolete term used for the kilocalorie, which is the calorie used to express the energy content of foods. However, in practice, the prefix ''kilo'' is usually omitted.

[13] Conversion factors for mercury manometer pressure units are calculated using the standard value for the acceleration of gravity and the density of mercury at the stated temperature. Additional digits are not justified because the definitions of the units do not take into account the compressibility of mercury or the change in density caused by the revised practical temperature scale, ITS-90. Similar comments also apply to water manometer pressure units. Conversion factors for conventional mercury and water manometer pressure units are based on ISO 31-3.

To convert from	to	Multiply by	
cubic inch (in^3)[14]	cubic meter (m^3)	1.638 706	E−05
cubic inch per minute (in^3/min)	cubic meter per second (m^3/s)	2.731 177	E−07
cubic mile (mi^3)	cubic meter (m^3)	4.168 182	E+09
cubic yard (yd^3)	cubic meter (m^3)	7.645 549	E−01
cubic yard per minute (yd^3/min)	cubic meter per second (m^3/s)	1.274 258	E−02
cup (U.S.)	cubic meter (m^3)	2.365 882	E−04
cup (U.S.)	liter (L)	2.365 882	E−01
cup (U.S.)	milliliter (mL)	2.365 882	E+02
curie (Ci)	becquerel (Bq)	**3.7**	**E+10**
darcy[15]	meter squared (m^2)	9.869 233	E−13
day (d)	second (s)	**8.64**	**E+04**
day (sidereal)	second (s)	8.616 409	E+04
debye (D)	coulomb meter (C · m)	3.335 641	E−30
degree (angle) (°)	radian (rad)	1.745 329	E−02
degree Celsius (temperature) (°C)	kelvin (K)	T/K = t/°C+**273.15**	
degree Celsius (temperature interval) (°C)	kelvin (K)	**1.0**	**E+00**
degree centigrade (temperature)[16]	degree Celsius (°C)	t/°C ≈ t/deg. cent.	
degree centigrade (temperature interval)[16]	degree Celsius (°C)	1.0	E+00
degree Fahrenheit (temperature) (°F)	degree Celsius (°C)	t/°C = (t/°F − **32**)/**1.8**	
degree Fahrenheit (temperature) (°F)	kelvin (K)	T/K = (t/°F + **459.67**)/**1.8**	
degree Fahrenheit (temperature interval) (°F)	degree Celsius (°C)	5.555 556	E−01
degree Fahrenheit (temperature interval) (°F)	kelvin (K)	5.555 556	E−01
degree Fahrenheit hour per British thermal unit$_{IT}$ (°F · h/Btu$_{IT}$)	kelvin per watt (K/W)	1.895 634	E+00
degree Fahrenheit hour per British thermal unit$_{th}$ (°F · h/Btu$_{th}$)	kelvin per watt (K/W)	1.896 903	E+00
degree Fahrenheit hour square foot per British thermal unit$_{IT}$ (°F · h · ft^2/Btu$_{IT}$)	square meter kelvin per watt (m^2 · K/W)	1.761 102	E−01
degree Fahrenheit hour square foot per British thermal unit$_{th}$ (°F · h · ft^2/Btu$_{th}$)	square meter kelvin per watt (m^2 · K/W)	1.762 280	E−01
degree Fahrenheit hour square foot per British thermal unit$_{IT}$ inch [°F · h · ft^2/(Btu$_{IT}$ · in)]	meter kelvin per watt (m · K/W)	6.933 472	E+00
degree Fahrenheit hour square foot per British thermal unit$_{th}$ inch [°F · h · ft^2/(Btu$_{th}$ · in)]	meter kelvin per watt (m · K/W)	6.938 112	E+00
degree Fahrenheit second per British thermal unit$_{IT}$ (°F · s/Btu$_{IT}$)	kelvin per watt (K/W)	5.265 651	E−04
degree Fahrenheit second per British thermal unit$_{th}$ (°F · s/Btu$_{th}$)	kelvin per watt (K/W)	5.269 175	E−04
degree Rankine (°R)	kelvin (K)	T/K = (T/°R)/**1.8**	
degree Rankine (temperature interval) (°R)	kelvin (K)	5.555 556	E−01
denier	kilogram per meter (kg/m)	1.111 111	E−07
denier	gram per meter (g/m)	1.111 111	E−04
dyne (dyn)	newton (N)	**1.0**	**E−05**
dyne centimeter (dyn · cm)	newton meter (N · m)	**1.0**	**E−07**
dyne per square centimeter (dyn/cm^2)	pascal (Pa)	**1.0**	**E−01**
electronvolt (eV)	joule (J)	1.602 177	E−19
EMU of capacitance (abfarad)	farad (F)	**1.0**	**E+09**
EMU of current (abampere)	ampere (A)	**1.0**	**E+01**
EMU of electric potential (abvolt)	volt (V)	**1.0**	**E−08**
EMU of inductance (abhenry)	henry (H)	**1.0**	**E−09**

[14] The exact conversion factor is 1.638 706 4 E−05.
[15] The darcy is a unit for expressing the permeability of porous solids, not area.
[16] The centigrade temperature scale is obsolete; the degree centigrade is only approximately equal to the degree Celsius.

To convert from	to	Multiply by	
EMU of resistance (abohm)	ohm (Ω)	**1.0**	**E−09**
erg (erg)	joule (J)	**1.0**	**E−07**
erg per second (erg/s)	watt (W)	**1.0**	**E−07**
erg per square centimeter second |1obrkt&1ru|/(cm^2 · s)]	watt per square meter (W/m^2)	**1.0**	**E−03**
ESU of capacitance (statfarad)	farad (F)	1.112 650	E−12
ESU of current (statampere)	ampere (A)	3.335 641	E−10
ESU of electric potential (statvolt)	volt (V)	2.997 925	E+02
ESU of inductance (stathenry)	henry (H)	8.987 552	E+11
ESU of resistance (statohm)	ohm (Ω)	8.987 552	E+11
faraday (based on carbon 12)	coulomb (C)	9.648 531	E+04
fathom (based on U.S. survey foot)[9]	meter (m)	1.828 804	E+00
fermi	meter (m)	**1.0**	**E−15**
fermi	femtometer (fm)	**1.0**	**E+00**
fluid ounce (U.S.) (fl oz)	cubic meter (m^3)	2.957 353	E−05
fluid ounce (U.S.) (fl oz)	milliliter (mL)	2.957 353	E+01
foot (ft)	meter (m)	**3.048**	**E−01**
foot (U.S. survey) (ft)[9]	meter (m)	3.048 006	E−01
footcandle	lux (lx)	1.076 391	E+01
footlambert	candela per square meter (cd/m^2)	3.426 259	E+00
foot of mercury, conventional (ftHg)[13]	pascal (Pa)	4.063 666	E+04
foot of mercury, conventional (ftHg)[13]	kilopascal (kPa)	4.063 666	E+01
foot of water (39.2 °F)[13]	pascal (Pa)	2.988 98	E+03
foot of water (39.2 °F)[13]	kilopascal (kPa)	2.988 98	E+00
foot of water, conventional (ftH_2O)[13]	pascal (Pa)	2.989 067	E+03
foot of water, conventional (ftH_2O)[13]	kilopascal (kPa)	2.989 067	E+00
foot per hour (ft/h)	meter per second (m/s)	8.466 667	E−05
foot per minute (ft/min)	meter per second (m/s)	**5.08**	**E−03**
foot per second (ft/s)	meter per second (m/s)	**3.048**	**E−01**
foot per second squared (ft/s^2)	meter per second squared (m/s^2)	**3.048**	**E−01**
foot poundal	joule (J)	4.214 011	E−02
foot pound-force (ft · lbf)	joule (J)	1.355 818	E+00
foot pound-force per hour (ft · lbf/h)	watt (W)	3.766 161	E−04
foot pound-force per minute (ft · lbf/min)	watt (W)	2.259 697	E−02
foot pound-force per second (ft · lbf/s)	watt (W)	1.355 818	E+00
foot to the fourth power (ft^4)[17]	meter to the fourth power (m^4)	8.630 975	E−03
franklin (Fr)	coulomb (C)	3.335 641	E−10
gal (Gal)	meter per second squared (m/s^2)	**1.0**	**E−02**
gallon [Canadian and U.K. (Imperial)] (gal)	cubic meter (m^3)	**4.546 09**	**E−03**
gallon [Canadian and U.K. (Imperial)] (gal)	liter (L)	**4.546 09**	**E+00**
gallon (U.S.) (gal)	cubic meter (m^3)	3.785 412	E−03
gallon (U.S.) (gal)	liter (L)	3.785 412	E+00
gallon (U.S.) per day (gal/d)	cubic meter per second (m^3/s)	4.381 264	E−08
gallon (U.S.) per day (gal/d)	liter per second (L/s)	4.381 264	E−05
gallon (U.S.) per horsepower hour [gal/(hp · h)]	cubic meter per joule (m^3/J)	1.410 089	E−09
gallon (U.S.) per horsepower hour [gal/(hp · h)]	liter per joule (L/J)	1.410 089	E−06
gallon (U.S.) per minute (gpm)(gal/min)	cubic meter per second (m^3/s)	6.309 020	E−05
gallon (U.S.) per minute (gpm)(gal/min)	liter per second (L/s)	6.309 020	E−02

[17] This is a unit for the quantity second moment of area, which is sometimes called the ''moment of section'' or ''area moment of inertia'' of a plane section about a specified axis.

To convert from	to	Multiply by	
gamma (γ)	tesla (T)	**1.0**	**E−09**
gauss (Gs, G)	tesla (T)	**1.0**	**E−04**
gilbert (Gi)	ampere (A)	7.957 747	E−01
gill [Canadian and U.K. (Imperial)] (gi)	cubic meter (m^3)	1.420 653	E−04
gill [Canadian and U.K. (Imperial)] (gi)	liter (L)	1.420 653	E−01
gill (U.S.) (gi)	cubic meter (m^3)	1.182 941	E−04
gill (U.S.) (gi)	liter (L)	1.182 941	E−01
gon (also called grade) (gon)	radian (rad)	1.570 796	E−02
gon (also called grade) (gon)	degree (angle) (°)	**9.0**	**E−01**
grain (gr)	kilogram (kg)	**6.479 891**	**E−05**
grain (gr)	milligram (mg)	**6.479 891**	**E+01**
grain per gallon (U.S.) (gr/gal)	kilogram per cubic meter (kg/m^3)	1.711 806	E−02
grain per gallon (U.S.) (gr/gal)	milligram per liter (mg/L)	1.711 806	E+01
gram-force per square centimeter (gf/cm^2)	pascal (Pa)	**9.806 65**	**E+01**
gram per cubic centimeter (g/cm^3)	kilogram per cubic meter (kg/m^3)	**1.0**	**E+03**
hectare (ha)	square meter (m^2)	**1.0**	**E+04**
horsepower (550 ft · lbf/s) (hp)	watt (W)	7.456 999	E+02
horsepower (boiler)	watt (W)	9.809 50	E+03
horsepower (electric)	watt (W)	**7.46**	**E+02**
horsepower (metric)	watt (W)	7.354 988	E+02
horsepower (U.K.)	watt (W)	7.4570	E+02
horsepower (water)	watt (W)	7.460 43	E+02
hour (h)	second (s)	**3.6**	**E+03**
hour (sidereal)	second (s)	3.590 170	E+03
hundredweight (long, 112 lb)	kilogram (kg)	5.080 235	E+01
hundredweight (short, 100 lb)	kilogram (kg)	4.535 924	E+01
inch (in)	meter (m)	**2.54**	**E−02**
inch (in)	centimeter (cm)	**2.54**	**E+00**
inch of mercury (32 °F)[13]	pascal (Pa)	3.386 38	E+03
inch of mercury (32 °F)[13]	kilopascal (kPa)	3.386 38	E+00
inch of mercury (60 °F)[13]	pascal (Pa)	3.376 85	E+03
inch of mercury (60 °F)[13]	kilopascal (kPa)	3.376 85	E+00
inch of mercury, conventional (inHg)[13]	pascal (Pa)	3.386 389	E+03
inch of mercury, conventional (inHg)[13]	kilopascal (kPa)	3.386 389	E+00
inch of water (39.2 °F)[13]	pascal (Pa)	2.490 82	E+02
inch of water (60 °F)[13]	pascal (Pa)	2.4884	E+02
inch of water, conventional (inH_2O)[13]	pascal (Pa)	2.490 889	E+02
inch per second (in/s)	meter per second (m/s)	**2.54**	**E−02**
inch per second squared (in/s^2)	meter per second squared (m/s^2)	**2.54**	**E−02**
inch to the fourth power (in^4)[17]	meter to the fourth power (m^4)	4.162 314	E−07
kayser (K)	reciprocal meter (m^{-1})	**1.0**	**E+02**
kelvin (K)	degree Celsius (°C)	$t/°C = T/K -$ **273.15**	
kilocalorie$_{IT}$ (kcal$_{IT}$)	joule (J)	**4.1868**	**E+03**
kilocalorie$_{th}$ (kcal$_{th}$)	joule (J)	**4.184**	**E+03**
kilocalorie (mean) (kcal)	joule (J)	4.190 02	E+03
kilocalorie$_{th}$ per minute (kcal$_{th}$/min)	watt (W)	6.973 333	E+01
kilocalorie$_{th}$ per second (kcal$_{th}$/s)	watt (W)	**4.184**	**E+03**
kilogram-force (kgf)	newton (N)	**9.806 65**	**E+00**
kilogram-force meter (kgf · m)	newton meter (N · m)	**9.806 65**	**E+00**

To convert from	to	Multiply by	
kilogram-force per square centimeter (kgf/cm^2)	pascal (Pa)	**9.806 65**	**E+04**
kilogram-force per square centimeter (kgf/cm^2)	kilopascal (kPa)	**9.806 65**	**E+01**
kilogram-force per square meter (kgf/m^2)	pascal (Pa)	**9.806 65**	**E+00**
kilogram-force per square millimeter (kgf/mm^2)	pascal (Pa)	**9.806 65**	**E+06**
kilogram-force per square millimeter (kgf/mm^2)	megapascal (MPa)	**9.806 65**	**E+00**
kilogram-force second squared per meter ($kgf \cdot s^2/m$)	kilogram (kg)	**9.806 65**	**E+00**
kilometer per hour (km/h)	meter per second (m/s)	2.777 778	E−01
kilopond (kilogram-force) (kp)	newton (N)	**9.806 65**	**E+00**
kilowatt hour (kW · h)	joule (J)	**3.6**	**E+06**
kilowatt hour (kW · h)	megajoule (MJ)	**3.6**	**E+00**
kip (1 kip=1000 lbf)	newton (N)	4.448 222	E+03
kip (1 kip=1000 lbf)	kilonewton (kN)	4.448 222	E+00
kip per square inch (ksi) (kip/in^2)	pascal (Pa)	6.894 757	E+06
kip per square inch (ksi) (kip/in^2)	kilopascal (kPa)	6.894 757	E+03
knot (nautical mile per hour)	meter per second (m/s)	5.144 444	E−01
lambert[18]	candela per square meter (cd/m^2)	3.183 099	E+03
langley (cal_{th}/cm^2)	joule per square meter (J/m^2)	**4.184**	**E+04**
light year (l.y.)[19]	meter (m)	9.460 73	E+15
liter (L)[20]	cubic meter (m^3)	**1.0**	**E−03**
lumen per square foot (lm/ft^2)	lux (lx)	1.076 391	E+01
maxwell (Mx)	weber (Wb)	**1.0**	**E−08**
mho	siemens (S)	**1.0**	**E+00**
microinch	meter (m)	**2.54**	**E−08**
microinch	micrometer (μm)	**2.54**	**E−02**
micron (μ)	meter (m)	**1.0**	**E−06**
micron (μ)	micrometer (μm)	**1.0**	**E+00**
mil (0.001 in)	meter (m)	**2.54**	**E−05**
mil (0.001 in)	millimeter (mm)	**2.54**	**E−02**
mil (angle)	radian (rad)	9.817 477	E−04
mil (angle)	degree (°)	**5.625**	**E−02**
mile (mi)	meter (m)	**1.609 344**	**E+03**
mile (mi)	kilometer (km)	**1.609 344**	**E+00**
mile (based on U.S. survey foot) (mi)[9]	meter (m)	1.609 347	E+03
mile (based on U.S. survey foot) (mi)[9]	kilometer (km)	1.609 347	E+00
mile, nautical[21]	meter (m)	**1.852**	**E+03**
mile per gallon (U.S.) (mpg) (mi/gal)	meter per cubic meter (m/m^3)	4.251 437	E+05
mile per gallon (U.S.) (mpg) (mi/gal)	kilometer per liter (km/L)	4.251 437	E−01
mile per gallon (U.S.) (mpg) (mi/gal)[22]	liter per 100 kilometer (L/100 km)	divide 235.215 by number of miles per gallon	
mile per hour (mi/h)	meter per second (m/s)	**4.4704**	**E−01**
mile per hour (mi/h)	kilometer per hour (km/h)	**1.609 344**	**E+00**

[18] The exact conversion factor is $10^4/\pi$.

[19] This conversion factor is based on 1 d = 86 400 s; and 1 Julian century = 36 525 d. (See *The Astronomical Almanac for the Year 1995*, page K6, U.S. Government Printing Office, Washington, DC, 1994).

[20] In 1964 the General Conference on Weights and Measures reestablished the name ''liter'' as a special name for the cubic decimeter. Between 1901 and 1964 the liter was slightly larger (1.000 028 dm^3); when one uses high-accuracy volume data of that time, this fact must be kept in mind.

[21] The value of this unit, 1 nautical mile = 1852 m, was adopted by the First International Extraordinary Hydrographic Conference, Monaco, 1929, under the name ''International nautical mile.''

[22] For converting fuel economy, as used in the U.S., to fuel consumption.

To convert from	to	Multiply by	
mile per minute (mi/min)	meter per second (m/s)	**2.682 24**	**E+01**
mile per second (mi/s)	meter per second (m/s)	**1.609 344**	**E+03**
millibar (mbar)	pascal (Pa)	**1.0**	**E+02**
millibar (mbar)	kilopascal (kPa)	**1.0**	**E−01**
millimeter of mercury, conventional (mmHg)[13]	pascal (Pa)	1.333 224	E+02
millimeter of water, conventional (mmH_2O)[13]	pascal (Pa)	**9.806 65**	**E+00**
minute (angle) (')	radian (rad)	2.908 882	E−04
minute (min)	second (s)	**6.0**	**E+01**
minute (sidereal)	second (s)	5.983 617	E+01
oersted (Oe)	ampere per meter (A/m)	7.957 747	E+01
ohm centimeter (Ω · cm)	ohm meter (Ω · m)	**1.0**	**E−02**
ohm circular-mil per foot	ohm meter (Ω · m)	1.662 426	E−09
ohm circular-mil per foot	ohm square millimeter per meter ($\Omega \cdot mm^2/m$)	1.662 426	E−03
ounce (avoirdupois) (oz)	kilogram (kg)	2.834 952	E−02
ounce (avoirdupois) (oz)	gram (g)	2.834 952	E+01
ounce (troy or apothecary) (oz)	kilogram (kg)	3.110 348	E−02
ounce (troy or apothecary) (oz)	gram (g)	3.110 348	E+01
ounce [Canadian and U.K. fluid (Imperial)] (fl oz)	cubic meter (m^3)	2.841 306	E−05
ounce [Canadian and U.K. fluid (Imperial)] (fl oz)	milliliter (mL)	2.841 306	E+01
ounce (U.S. fluid) (fl oz)	cubic meter (m^3)	2.957 353	E−05
ounce (U.S. fluid) (fl oz)	millimeter (mL)	2.957 353	E+01
ounce (avoirdupois)-force (ozf)	newton (N)	2.780 139	E−01
ounce (avoirdupois)-force inch (ozf · in)	newton meter (N · m)	7.061 552	E−03
ounce (avoirdupois)-force inch (ozf · in)	millinewton meter (mN · m)	7.061 552	E+00
ounce (avoirdupois) per cubic inch (oz/in^3)	kilogram per cubic meter (kg/m^3)	1.729 994	E+03
ounce (avoirdupois) per gallon [Canadian and U.K. (Imperial)] (oz/gal)	kilogram per cubic meter (kg/m^3)	6.236 023	E+00
ounce (avoirdupois) per gallon [Canadian and U.K. (Imperial)] (oz/gal)	gram per liter (g/L)	6.236 023	E+00
ounce (avoirdupois) per gallon (U.S.) (oz/gal)	kilogram per cubic meter (kg/m^3)	7.489 152	E+00
ounce (avoirdupois) per gallon (U.S.) (oz/gal)	gram per liter (g/L)	7.489 152	E+00
ounce (avoirdupois) per square foot (oz/ft^2)	kilogram per square meter (kg/m^2)	3.051 517	E−01
ounce (avoirdupois) per square inch (oz/in^2)	kilogram per square meter (kg/m^2)	4.394 185	E+01
ounce (avoirdupois) per square yard (oz/yd^2)	kilogram per square meter (kg/m^2)	3.390 575	E−02
parsec (pc)	meter (m)	3.085 678	E+16
peck (U.S.) (pk)	cubic meter (m^3)	8.809 768	E−03
peck (U.S.) (pk)	liter (L)	8.809 768	E+00
pennyweight (dwt)	kilogram (kg)	1.555 174	E−03
pennyweight (dwt)	gram (g)	1.555 174	E+00
perm (0 °C)	kilogram per pascal second square meter [$kg/(Pa \cdot s \cdot m^2)$]	5.721 35	E−11
perm (23 °C)	kilogram per pascal second square meter [$kg/(Pa \cdot s \cdot m^2)$]	5.745 25	E−11
perm inch (0 °C)	kilogram per pascal second meter [kg/(Pa · s · m)]	1.453 22	E−12
perm inch (23 °C)	kilogram per pascal second meter [kg/(Pa · s · m)]	1.459 29	E−12

To convert from	to	Multiply by	
phot (ph)	lux (lx)	**1.0**	**E+04**
pica (computer) (1/6 in)	meter (m)	4.233 333	E−03
pica (computer) (1/6 in)	millimeter (mm)	4.233 333	E+00
pica (printer's)	meter (m)	4.217 518	E−03
pica (printer's)	millimeter (mm)	4.217 518	E+00
pint (U.S. dry) (dry pt)	cubic meter (m^3)	5.506 105	E−04
pint (U.S. dry) (dry pt)	liter (L)	5.506 105	E−01
pint (U.S. liquid) (liq pt)	cubic meter (m^3)	4.731 765	E−04
pint (U.S. liquid) (liq pt)	liter (L)	4.731 765	E−01
point (computer) (1/72 in)	meter (m)	3.527 778	E−04
point (computer) (1/72 in)	millimeter (mm)	3.527 778	E−01
point (printer's)	meter (m)	3.514 598	E−04
point (printer's)	millimeter (mm)	3.514 598	E−01
poise (P)	pascal second (Pa · s)	**1.0**	**E−01**
pound (avoirdupois) (lb)[23]	kilogram (kg)	4.535 924	E−01
pound (troy or apothecary) (lb)	kilogram (kg)	3.732 417	E−01
poundal	newton (N)	1.382 550	E−01
poundal per square foot	pascal (Pa)	1.488 164	E+00
poundal second per square foot	pascal second (Pa · s)	1.488 164	E+00
pound foot squared (lb · ft^2)	kilogram meter squared (kg · m^2)	4.214 011	E−02
pound-force (lbf)[24]	newton (N)	4.448 222	E+00
pound-force foot (lbf · ft)	newton meter (N · m)	1.355 818	E+00
pound-force foot per inch (lbf · ft/in)	newton meter per meter (N · m/m)	5.337 866	E+01
pound-force inch (lbf · in)	newton meter (N · m)	1.129 848	E−01
pound-force inch per inch (lbf · in/in)	newton meter per meter (N · m/m)	4.448 222	E+00
pound-force per foot (lbf/ft)	newton per meter (N/m)	1.459 390	E+01
pound-force per inch (lbf/in)	newton per meter (N/m)	1.751 268	E+02
pound-force per pound (lbf/lb) (thrust to mass ratio)	newton per kilogram (N/kg)	**9.806 65**	**E+00**
pound-force per square foot (lbf/ft^2)	pascal (Pa)	4.788 026	E+01
pound-force per square inch (psi) (lbf/in^2)	pascal (Pa)	6.894 757	E+03
pound-force per square inch (psi) (lbf/in^2)	kilopascal (kPa)	6.894 757	E+00
pound-force second per square foot (lbf · s/ft^2)	pascal second (Pa · s)	4.788 026	E+01
pound-force second per square inch (lbf · s/in^2)	pascal second (Pa · s)	6.894 757	E+03
pound inch squared (lb · in^2)	kilogram meter squared (kg · m^2)	2.926 397	E−04
pound per cubic foot (lb/ft^3)	kilogram per cubic meter (kg/m^3)	1.601 846	E+01
pound per cubic inch (lb/in^3)	kilogram per cubic meter (kg/m^3)	2.767 990	E+04
pound per cubic yard (lb/yd^3)	kilogram per cubic meter (kg/m^3)	5.932 764	E−01
pound per foot (lb/ft)	kilogram per meter (kg/m)	1.488 164	E+00
pound per foot hour [lb/(ft · h)]	pascal second (Pa · s)	4.133 789	E−04
pound per foot second [lb/(ft · s)]	pascal second (Pa · s)	1.488 164	E+00
pound per gallon [Canadian and U.K. (Imperial)] (lb/gal)	kilogram per cubic meter (kg/m^3)	9.977 637	E+01
pound per gallon [Canadian and U.K. (Imperial)] (lb/gal)	kilogram per liter (kg/L)	9.977 637	E−02
pound per gallon (U.S.) (lb/gal)	kilogram per cubic meter (kg/m^3)	1.198 264	E+02
pound per gallon (U.S.) (lb/gal)	kilogram per liter (kg/L)	1.198 264	E−01
pound per horsepower hour [lb/(hp · h)]	kilogram per joule (kg/J)	1.689 659	E−07
pound per hour (lb/h)	kilogram per second (kg/s)	1.259 979	E−04

[23] The exact conversion factor is 4.535 923 7 E−01. All units that contain the pound refer to the avoirdupois pound.

[24] If the local value of the acceleration of free fall is taken as $g_n = 9.806\ 65\ m/s^2$ (the standard value), the exact conversion factor is 4.448 221 615 260 5 E+00.

To convert from	to	Multiply by	
pound per inch (lb/in)	kilogram per meter (kg/m)	1.785 797	E+01
pound per minute (lb/min)	kilogram per second (kg/s)	7.559 873	E−03
pound per second (lb/s)	kilogram per second (kg/s)	4.535 924	E−01
pound per square foot (lb/ft^2)	kilogram per square meter (kg/m^2)	4.882 428	E+00
pound per square inch (*not* pound-force) (lb/in^2)	kilogram per square meter (kg/m^2)	7.030 696	E+02
pound per yard (lb/yd)	kilogram per meter (kg/m)	4.960 546	E−01
psi (pound-force per square inch) (lbf/in^2)	pascal (Pa)	6.894 757	E+03
psi (pound-force per square inch) (lbf/in^2)	kilopascal (kPa)	6.894 757	E+00
quad (10^{15} Btu_{IT})[11]	joule (J)	1.055 056	E+18
quart (U.S. dry) (dry qt)	cubic meter (m^3)	1.101 221	E−03
quart (U.S. dry) (dry qt)	liter (L)	1.101 221	E+00
quart (U.S. liquid) (liq qt)	cubic meter (m^3)	9.463 529	E−04
quart (U.S. liquid) (liq qt)	liter (L)	9.463 529	E−01
rad (absorbed dose) (rad)	gray (Gy)	**1.0**	**E−02**
rem (rem)	sievert (Sv)	**1.0**	**E−02**
revolution (r)	radian (rad)	6.283 185	E+00
revolution per minute (rpm) (r/min)	radian per second (rad/s)	1.047 198	E−01
rhe	reciprocal pascal second [(Pa · s)$^{-1}$]	**1.0**	**E+01**
rod (based on U.S. survey foot) (rd)[9]	meter (m)	5.029 210	E+00
roentgen (R)	coulomb per kilogram (C/kg)	**2.58**	**E−04**
rpm (revolution per minute) (r/min)	radian per second (rad/s)	1.047 198	E−01
second (angle) (")	radian (rad)	4.848 137	E−06
second (sidereal)	second (s)	9.972 696	E−01
shake	second (s)	**1.0**	**E−08**
shake	nanosecond (ns)	**1.0**	**E+01**
slug (slug)	kilogram (kg)	1.459 390	E+01
slug per cubic foot (slug/ft^3)	kilogram per cubic meter (kg/m^3)	5.153 788	E+02
slug per foot second [slug/(ft · s)]	pascal second (Pa · s)	4.788 026	E+01
square foot (ft^2)	square meter (m^2)	**9.290 304**	**E−02**
square foot per hour (ft^2/h)	square meter per second (m^2/s)	**2.580 64**	**E−05**
square foot per second (ft^2/s)	square meter per second (m^2/s)	**9.290 304**	**E−02**
square inch (in^2)	square meter (m^2)	**6.4516**	**E−04**
square inch (in^2)	square centimeter (cm^2)	**6.4516**	**E+00**
square mile (mi^2)	square meter (m^2)	2.589 988	E+06
square mile (mi^2)	square kilometer (km^2)	2.589 988	E+00
square mile (based on U.S. survey foot) (mi^2)[9]	square meter (m^2)	2.589 998	E+06
square mile (based on U.S. survey foot) (mi^2)[9]	square kilometer (km^2)	2.589 998	E+00
square yard (yd^2)	square meter (m^2)	8.361 274	E−01
statampere	ampere (A)	3.335 641	E−10
statcoulomb	coulomb (C)	3.335 641	E−10
statfarad	farad (F)	1.112 650	E−12
stathenry	henry (H)	8.987 552	E+11
statmho	siemens (S)	1.112 650	E−12
statohm	ohm (Ω)	8.987 552	E+11
statvolt	volt (V)	2.997 925	E+02
stere (st)	cubic meter (m^3)	**1.0**	**E+00**
stilb (sb)	candela per square meter (cd/m^2)	**1.0**	**E+04**
stokes (St)	meter squared per second (m^2/s)	**1.0**	**E−04**

To convert from	to	Multiply by	
tablespoon	cubic meter (m^3)	1.478 676	E−05
tablespoon	milliliter (mL)	1.478 676	E+01
teaspoon	cubic meter (m^3)	4.928 922	E−06
teaspoon	milliliter (mL)	4.928 922	E+00
tex	kilogram per meter (kg/m)	**1.0**	**E−06**
therm (EC)[25]	joule (J)	**1.055 06**	**E+08**
therm (U.S.)[25]	joule (J)	**1.054 804**	**E+08**
ton, assay (AT)	kilogram (kg)	2.916 667	E−02
ton, assay (AT)	gram (g)	2.916 667	E+01
ton-force (2000 lbf)	newton (N)	8.896 443	E+03
ton-force (2000 lbf)	kilonewton (kN)	8.896 443	E+00
ton, long (2240 lb)	kilogram (kg)	1.016 047	E+03
ton, long, per cubic yard	kilogram per cubic meter (kg/m^3)	1.328 939	E+03
ton, metric (t)	kilogram (kg)	**1.0**	**E+03**
tonne (called ''metric ton'' in U.S.) (t)	kilogram (kg)	**1.0**	**E+03**
ton of refrigeration (12 000 Btu_{IT}/h)	watt (W)	3.516 853	E+03
ton of TNT (energy equivalent)[26]	joule (J)	**4.184**	**E+09**
ton, register	cubic meter (m^3)	2.831 685	E+00
ton, short (2000 lb)	kilogram (kg)	9.071 847	E+02
ton, short, per cubic yard	kilogram per cubic meter (kg/m^3)	1.186 553	E+03
ton, short, per hour	kilogram per second (kg/s)	2.519 958	E−01
torr (Torr)	pascal (Pa)	1.333 224	E+02
unit pole	weber (Wb)	1.256 637	E−07
watt hour (W · h)	joule (J)	**3.6**	**E+03**
watt per square centimeter (W/cm^2)	watt per square meter (W/m^2)	**1.0**	**E+04**
watt per square inch (W/in^2)	watt per square meter (W/m^2)	1.550 003	E+03
watt second (W · s)	joule (J)	**1.0**	**E+00**
yard (yd)	meter (m)	**9.144**	**E−01**
year (365 days)	second (s)	**3.1536**	**E+07**
year (sidereal)	second (s)	3.155 815	E+07
year (tropical)	second (s)	3.155 693	E+07

[25] The therm (EC) is legally defined in the Council Directive of 20 December 1979. Council of the European Communities (now the European Union, EU). The Therm (U.S.) is legally defined in the Federal Register of July 27, 1968. Although the therm (EC), which is based on the International Table Btu, is frequently used by engineers in the United States, the therm (U.S.) is the legal unit used by the U.S. natural gas industry.

[26] Defined (not measured) value.

From *CRC Handbook of Chemistry & Physics,* 83rd ed., Lide, D., Ed., CRC Press, Boca Raton, FL, 2002, pp. **1**-34 to **1**-45.

PERIODIC TABLE OF THE ELEMENTS

New Notation / Previous IUPAC Form / CAS Version

Key to Chart

Atomic Number → 50; Symbol → Sn; Oxidation States → +2 +4; 1995 Atomic Weight → 118.710; Electron Configuration → -18-18-4

1 Group IA	2 IIA	3 IIIA IIIB	4 IVA IVB	5 VA VB	6 VIA VIB	7 VIIA VIIB	8 VIIIA VIII	9 VIIIA VIII	10 VIIIA VIII	11 IB IB	12 IIB IIB	13 IIIB IIIA	14 IVB IVA	15 VB VA	16 VIB VIA	17 VIIB VIIA	18 VIIIA	Shell
1 H +1 -1 1.00794 1																	2 He 0 4.002602 2	K
3 Li +1 6.941 2-1	4 Be +2 9.012182 2-2											5 B +3 10.811 2-3	6 C +2 +4 -4 12.0107 2-4	7 N +1 +2 +3 +4 +5 -1 -2 -3 14.0067 2-5	8 O -2 15.9994 2-6	9 F -1 18.9984032 2-7	10 Ne 0 20.1797 2-8	K-L
11 Na +1 22.989770 2-8-1	12 Mg +2 24.3050 2-8-2											13 Al +3 26.981538 2-8-3	14 Si +2 +4 -4 28.0855 2-8-4	15 P +3 +5 -3 30.973761 2-8-5	16 S +4 +6 -2 32.065 2-8-6	17 Cl +1 +5 +7 -1 35.453 2-8-7	18 Ar 0 39.948 2-8-8	K-L-M
19 K +1 39.0983 -8-8-1	20 Ca +2 40.078 -8-8-2	21 Sc +3 44.955910 -8-9-2	22 Ti +2 +3 +4 47.867 -8-10-2	23 V +2 +3 +4 +5 50.9415 -8-11-2	24 Cr +2 +3 +6 51.9961 -8-13-1	25 Mn +2 +3 +4 +7 54.938049 -8-13-2	26 Fe +2 +3 55.845 -8-14-2	27 Co +2 +3 58.933200 -8-15-2	28 Ni +2 +3 58.6934 -8-16-2	29 Cu +1 +2 63.546 -8-18-1	30 Zn +2 65.409 -8-18-2	31 Ga +3 69.723 -8-18-3	32 Ge +2 +4 72.64 -8-18-4	33 As +3 +5 -3 74.92160 -8-18-5	34 Se +4 +6 -2 78.96 -8-18-6	35 Br +1 +5 -1 79.904 -8-18-7	36 Kr 0 83.798 -8-18-8	-L-M-N
37 Rb +1 85.4678 -18-8-1	38 Sr +2 87.62 -18-8-2	39 Y +3 88.90585 -18-9-2	40 Zr +4 91.224 -18-10-2	41 Nb +3 +5 92.90638 -18-12-1	42 Mo +6 95.94 -18-13-1	43 Tc +4 +6 +7 (98) -18-13-2	44 Ru +3 101.07 -18-15-1	45 Rh +3 102.90550 -18-16-1	46 Pd +2 +3 106.42 -18-18-0	47 Ag +1 107.8682 -18-18-1	48 Cd +2 112.411 -18-18-2	49 In +3 114.818 -18-18-3	50 Sn +2 +4 118.710 -18-18 -4	51 Sb +3 +5 -3 121.760 -18-18-5	52 Te +4 +6 -2 127.60 -18-18-6	53 I +1 +5 +7 -1 126.90447 -18-18-7	54 Xe 0 131.293 -18-18-8	-M-N-O
55 Cs +1 132.90545 -18-8-1	56 Ba +2 137.327 -18-8-2	57* La +3 138.9055 -18-9-2	72 Hf +4 178.49 -32-10-2	73 Ta +5 180.9479 -32-11-2	74 W +6 183.84 -32-12-2	75 Re +4 +6 +7 186.207 -32-13-2	76 Os +3 +4 190.23 -32-14-2	77 Ir +3 +4 192.217 -32-15-2	78 Pt +2 +4 195.078 -32-17-1	79 Au +1 +3 196.96655 -32-18-1	80 Hg +1 +2 200.59 -32-18-2	81 Tl +1 +3 204.3833 -32-18-3	82 Pb +2 +4 207.2 -32-18-4	83 Bi +3 +5 208.98038 -32-18-5	84 Po +2 +4 (209) -32-18-6	85 At (210) -32-18-7	86 Rn 0 (222) -32-18-8	-N-O-P
87 Fr +1 (223) -18-8-1	88 Ra +2 (226) -18-8-2	89** Ac +3 (227) -18-9-2	104 Rf +4 (261) -32-10-2	105 Db (262) -32-11-2	106 Sg (266) -32-12-2	107 Bh (264) -32-13-2	108 Hs (277) -32-14-2	109 Mt (268) -32-15-2	110 Uun (281) -32-16-2	111 Uuu (272)	112 Uub (285)		114 Uuq (289)		116 Uuh (289)			-O-P-Q

* Lanthanides	58 Ce +3 +4 140.116 -19-9-2	59 Pr +3 140.90765 -21-8-2	60 Nd +3 144.24 -22-8-2	61 Pm +3 (145) -23-8-2	62 Sm +2 +3 150.36 -24-8-2	63 Eu +2 +3 151.964 -25-8-2	64 Gd +3 157 .25 -25-9-2	65 Tb +3 158.92534 -27-8-2	66 Dy +3 162.500 -28-8-2	67 Ho +3 164.93032 -29-8-2	68 Er +3 167.259 -30-8-2	69 Tm +3 168.93421 -31-8-2	70 Yb +2 +3 173.04 -32-8-2	71 Lu +3 174.967 -32-9-2	-N-O-P
** Actinides	90 Th +4 232.0381 -18-10-2	91 Pa +5 +4 231.03588 -20-9-2	92 U +3 +4 +5 +6 238.02891 -21-9-2	93 Np +3 +4 +5 +6 (237) -22-9-2	94 Pu +3 +4 +5 +6 (244) -24-8-2	95 Am +3 +4 +5 +6 (243) -25-8-2	96 Cm +3 (247) -25-9-2	97 Bk +3 +4 (247) -27-8-2	98 Cf +3 (251) -28-8-2	99 Es +3 (252) -29-8-2	100 Fm +3 (257) -30-8-2	101 Md +2 +3 (258) -31-8-2	102 No +2 +3 (259) -32-8-2	103 Lr +3 (262) -32-8-3	-O-P-Q

The new IUPAC format numbers the groups from 1 to 18. The previous IUPAC numbering system and the system used by Chemical Abstracts Service (CAS) are als o shown. For radioactive elements that do not occur in nature, the mass number of the most stable isotope is given in parentheses.

References

1. G. J. Leigh, Editor, *Nomenclature of Inorganic Chemistry*, Blackwell Scientific Publications, Oxford, 1990.
2. *Chemical and Engineering News*, 63(5), 27, 1985.
3. Atomic Weights of the Elements, 1999, *Pure & Appl. Chem.*, 73, 667, 2001.

From *CRC Handbook of Chemistry and Physics,* 83rd ed., Lide, O., Ed., CRC Press, Boca Raton, FL, 2002.

Properties of Semiconductors

The term *semiconductor* is applied to a material in which electric current is carried by electrons or holes and whose electrical conductivity, when extremely pure, rises exponentially with temperature and may be increased from its low "intrinsic" value by many orders of magnitude by "doping" with electrically active impurities.

Semiconductors are characterized by an energy gap in the allowed energies of electrons in the material which separates the normally filled energy levels of the *valence band* (where "missing" electrons behave like positively charged current carriers "holes") and the *conduction band* (where electrons behave rather like a gas of free negatively charged carriers with an effective mass dependent on the material and the direction of the electrons' motion). This energy gap depends on the nature of the material and varies with direction in anisotropic crystals. It is slightly dependent on temperature and pressure, and this dependence is usually almost linear at normal temperatures and pressures.

Data are presented in three tables. Table I "General Properties of Semiconductors" lists the main crystallographic and semiconducting properties of a large number of semiconducting materials in three main categories: "Tetrahedral Semiconductors" in which every atom is tetrahedrally co-ordinated to four nearest neighbor atoms (or atomic sites) as for example in the diamond structure; "Octahedral Semiconductors: in which every atom is octahedrally co-ordinated to six nearest neighbor atoms—as for examples the halite structure; and "Other Semiconductors."

Table II gives more detailed information about some better known semiconductors, while Table III gives some information about the electronic energy band structure parameters of the best known materials.

Table I.
PHYSICO-CHEMICAL PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE)

Substance	Molecular Mass	Average Atomic Mass	Lattice Parameters (Å, Room Temp.)	Density (g/cm^3)	Melting Point (K)	Microhardness, N/mm^2 (M-Mohs Scale)	Specific Heat, J/kg·K (300 K)	Debye Temp. (K)	Coefficient of Thermal Linear Expansion [10^{-6} K^{-1} (300K)]	Thermal Conductivity [mW/cm·K (300K)]
Part A. Adamantine Semiconductors										
§A1. Diamond Structure Elements (Strukturbericht symbol A4, Space Group Fd3m-O_h^7)										
C		12.01	3.56683	3.51	≈3850 Transition to graphite > 980	10 (M)	471.5	2340	1.18	9900(I) 23200(IIA) 13600(IIB)
Si		28.09	5.43072	2.3283	1685 ± 2	11270	702	645	2.49	1240
Ge		72.59	5.65754	5.3234	1231	7644	321.9	374	6.1	640
α-Sn		118.69	6.4912	5.765 (281 K)	505.2 (Tr. 286.4)		213	230	5.4 (220 K)	

§A2. Sphalerite (Zinc Blende) Structure Compounds (Strukturbericht symbo1 B3 Space Group F $\bar{4}$ 3m-T_d^2)

I VII Compounds										
CuF	82.54	41.27	4.255		1181					
CuCl	98.99	49.49	5.4057	3.53	695	2.3 (M)	490	240	12.1	8.4
CuBr	143.36	71.73	5.6905	4.98	770	2.5 (M)	381	207	15.4	12.5
Cul	190.46	95.23	6.60427	5.63	878	192	276	181	19.2	16.8
AgBr	187.78	93.89		6.473	>1570 (Tr. 410)	2.5 (M)	270			
AgI	234.77	117.39	6.502	5.67	831	2.5 (M)	232	134	–2.5	4.2
II VI Compounds										
BeS	41.08	20.54	4.865	2.36						
BeSe	87.97	43.99	5.139	4.315						
BeTe	136.61	68.31	5.626	5.090						
BePo	(2318)	(109)	5.838	7.3						
ZnO	81.37	40.69	4.63	5.675	2248	5.0 (M)	494	416	2.9	234
ZnS	97.43	48.72	5.4093	4.079	2100 (Tr. 1295)	1780	472	530	6.36	251
ZnSe	144.34	72.17	5.6676	5.42	1790	1350	339	400	7.2	140
ZnTe	192.99	96.5	6.101	6.34	1568	900	264	223	8.19	108
ZnPo	(274)	(137)	6.309							
CdS	144.46	72.23	5.832	4.826	1750	1250	330	219	4.7	200
CdSe	191.36	95.68	6.05	5.674	1512	1300	255	181	3.8	90
CdTe	240.00	120.00	6.477	5.86	1365	600	205	200	4.9	58.5
CdPo	(321)	(161)	6.665							
HgS	232.65	116.33	5.8517	7.73	1820	3 (M)	210			
HgSe	279.55	139.78	6.084	8.25	1070	2.5 (M)	178	151	5.46	10
HgTe	328.19	164.10	6.4623	8.17	943	300	164	242	4.6	20
III V Compounds										
BN	24.82	12.41	3.615	3.49	≈3300	10 (M)	793	≈1900		200
BP(L.T.)	41.78	20.87	4.538	2.9	≈2800	37000		≈980		
BAs	85.73	42.87	4.777		≈2300	19000		≈625		
AIP	57.95	28.98	5.451	2.42	≈2100	5.5 (M)		588		920
AIAs	101.90	50.95	5.6622	3.81	2013	5000		417	3.5	840
AISb	148.73	74.37	6.1355	4.218	1330	4000		292	4.2	600
GaP	100.69	50.35	5.4905	4.13	1750	9450		446	5.3	752
GaAs	144.64	72.32	5.65315	5.316	1510	7500		344	5.4	560
GaSb	191.47	95.74	6.0954	5.619	980	4480	320	265	6.1	270
InP	145.79	72.90	5.86875	4.787	1330	4100		321	4.6	800
InAs	189.74	94.87	6.05838	5.66	1215	3300	268	249	4.7	290
InSb	236.57	118.29	6.47877	5.775	798	2200	144	202	4.7	160

Table I.
PHYSICO-CHEMICAL PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

Substance	Molecular Mass	Average Atomic Mass	Lattice Parameters (Å, Room Temp.)		Density (g/cm³)	Melting Point (K)	Microhardness, N/mm² (M-Mohs Scale)	Specific Heat, J/kg·K (300 K)	Debye Temp. (K)	Coefficient of Thermal Linear Expansion [10^{-6} K^{-1} (300K)]	Thermal Conductivity [mW/cm·K (300K)]
Other sphalerite structure compounds											
MnS	87.0	43.5	5.011								
MnSe	133.9	66.95	5.82								
β-SiC	40.1	20.1	4.348		3.21	3070					
Ga_2Se_3	376.32	75.26	5.429		4.92	1020	3160			8.9	50
Ga_2Te_3	522.24	104.45	5.899		5.75	1063	2370				47
In_2Te_3(H.T.)	608.44	121.7	61.50		5.8	940	1660				69
$MgGeP_2$	158.84	39.71	5.652								
$ZnSnP_2$	246.00	61.5	5.65			1200					
$ZnSnAs_2$(H.T.)	333.90	82.38	5.851		5.53	1050					76
$ZnSnSb_2$	427.56	106.89	6.281		5.67	870	2500				76
§A3. Wurtzite (Zincite) Structure Compounds (Strukturbericht symbol B4, Space Group P 6_3mc-C^4_{6v})											
I VII Compounds											
CuCl	99.0	49.5	3.91	6.42		T_c680K					
CuBr	143.46	71.73	4.06	6.66		T_c658K					
Cul	190.46	95.23	4.31	7.09							
Agl	234.80	117.40	4.580	7.494							
II VI Compounds											
BeO	25.01	12.51	2.698	4.380		2800					
MgTe	151.9	76.0	4.54	7.39	3.85	≈2800					
Zno	81.37	40.69	3.24950	5.2069	5.66	2250					600
ZnS	97.43	48.72	3.8140	6.2576	4.1	2100					460
ZnTe	192.99	46.50	4.27	6.99		1568					
Cds	144.46	72.23	4.1348	6.7490	4.82	1748					401
CdSe	191.36	95.68	4.299	7.010	5.66	1512					316
CdTe	240.00	120.00	4.57	7.47							
III V Compounds											
BP(H.T.)	41.79	20.90	3.562	5.900							
AIN	40.99	20.50	3.111	4.978	3.26	≈2500					823
GaN	83.73	41.87	3.190	5.189	6.10	1500					656
InN	128.83	64.42	3.533	5.693	6.88	1200					556

Other wurtzite structure compounds										
MnS	87.0	43.5	3.985	6.45	3.248					
MnSe	133.9	66.95	4.12	6.72						
SiC	40.1	20.1	3.076	5.048						
MnTe	182.54	91.27	4.078	6.701						
Al_2S_3	150.14	30.03	3.579	5.829	2.55	1400				
Al_2Se_3	290.84	58.17	3.890	6.30	3.91	1250				

§A4. Chalcopyrite Structure Compounds (Strukturbericht symbol $E1_1$, Space Group I $\bar{4}$ 2d-D^{12}_{24})

I III VI_2 Compounds										
$CuAlS_2$	154.65	38.66	5.323	10.44	3.47	2500				
$CuAlSe_2$	248.45	62.11	5.617	10.92	4.70	2260				
$CuAlTe_2$	345.73	86.43	5.976	11.80	5.50	2550				
$CuGaS_2$	197.39	49.53	5.360	10.49	4.35	2300				
$CuGaSe_2$	291.19	72.80	5.618	11.01	5.56	1970	4200	275	5.4	42
$CuGaTe_2$	388.47	97.12	6.013	11.93	5.99	2400	3500		6.9	27
$CuInS_2$	242.49	60.62	5.528	11.08	4.75	1400	2550			
$CuInSe_2$	336.29	84.07	5.785	11.56	5.77	1600	2050		6.6	37
$CuInTe_2$	433.57	108.39	6.179	12.365	6.10	1660	400	195	7.1	49
$CuTlS_2$	322.05	83.01	5.580	11.17	6.32					
$CuTlSe_2$(L.T.)	425.85	106.46	5.844	11.65	7.11	900				
$CuFeS_2$	183.51	45.88	5.25	10.32	4.088					
$CuFeSe_2$	277.31	69.33				850				
$CuLaS_2$	266.58	66.65	5.65	10.86						
$AgAlS_2$	198.97	49.74	5.707	10.28	3.94					
$AgAlSe_2$	292.77	73.19	5.968	10.77	5.07	1220				
$AgAlTe_2$	390.05	97.51	6.309	11.85	6.18	1000				
$AgGaS_2$	241.71	60.43	5.755	10.28	4.72					
$AgGaSe_2$	335.51	83.88	5.985	10.90	5.84	1120	4400			
$AgGaTe_2$	432.79	108.2	6.301	11.96	6.05	990	1800	212		10
$AgInS_2$(L.T.)	286.87	71.70	5.828	11.19	5.00		2250			
$AgInSe_2$	380.61	95.15	6.102	11.69	5.81	1053	1850			30
$AgInTe_2$	477.89	119.47	6.42	12.59	6.12	965			9.49, 0.69	
$AgFeS_2$	227.83	56.96	5.66	10.30	4.53					
II IV V_2 Compounds										
$ZnSiP_2$	155.40	38.85	5.400	10.441	3.39	1640	1100			
$ZnGeP_2$	199.90	49.98	5.465	10.771	4.17	1295	8100			180
$ZnSnP_2$	246.00	61.5					6500			
$CdSiP_2$	202.43	50.61	5.678	10.431	4.00	≈1470	10500	282		
$CdGeP_2$	246.94	61.74	5.741	10.775	4.48	1049	5650			110

Table I.
PHYSICO-CHEMICAL PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

Substance	Molecular Mass	Average Atomic Mass	Lattice Parameters (Å, Room Temp.)		Density (g/cm^3)	Melting Point (K)	Microhardness, N/mm^2 (M-Mohs Scale)	Specific Heat, J/kg·K (300 K)	Debye Temp. (K)	Coefficient of Thermal Linear Expansion [10^{-6} K^{-1} (300K)]	Thermal Conductivity [mW/cm·K (300K)]
$CdSnP_2$	243.03	73.26	5.900	11.518			5000		195		140
$ZnSiAs_2$	242.20	60.55	5.61	10.88	4.70	1311	9200				
$ZnGeAs_2$	287.80	71.95	5.672	11.153	5.32	1150	6800		263		110
$ZnSnAs_2$	333.90	83.48	5.8515	11.704	5.53	1048	4550		271		150
$CdSiAs_2$	290.34	72.58	5.884	10.882			6850				
$CdGeAs_2$	334.83	83.71	5.9427	11.2172	5.60	938	4700				48
$CdSnAs_2$	380.93	95.23	6.0944	11.9182	5.72	880	3450				40
§A5. Other Ternary Semiconductors with Tetrahedral Coordination											
I_2 IV VI_3 Compounds											
Cu_2SiS_3(H.T.)	251.36	41.89	3.684	6.004	3.81	1200					23
Cu_2SiS_3(L.T.)			5.290	10.156	3.63						
Cu_2SiTe_3	537.98	89.66	5.93		5.47						
Cu_2GeS_3(H.T.)	295.88	49.31	5.317		4.45	1210	4550	510	254	7.2	12
Cu_2GeS_3(L.T.)			5.327	5.215	4.46						
Cu_2GeSe_3	436.56	72.76	5.589	5.485	5.57	1030	3840	340	168	8.4	24
Cu_2GeTe_3	582.51	97.09	5.958	5.935	5.92		2890				130
Cu_2SnS_3	341.98	57.00	5.436		5.02	1110	2770	440	214	7.8	28
$CuSnSe_3$	482.66	80.44	5.687		5.94	960	2510	310	148	8.9	35
Cu_2SnTe_3	628.61	104.77	6.048		6.51	680	1970				144
Ag_2GeSe_3	525.21	87.54									
Ag_2SnSe_3	571.31	95.22									
Ag_2GeTe_3	671.13	111.86									
Ag_2SnTe_3	717.23	119.54									
I_3 V VI_4 Compounds											
Cu_3PS_4	349.85	40.73	7.44	6.19							
Cu_3AsS_4	393.79	49.22	6.43	6.14	4.37					3.2	30.2
Cu_3AsSe_4	581.37	72.67	5.570	10.957	5.61				169	9.5	19
Cu_3SbS_4	440.64	55.08	5.38	16.76	4.90						
Cu_3SbSe_4	628.22	78.53	5.654	11.256	6.0				131	12.4	14.6
I IV_2 V_3 Compounds											
$CuSi_2P_3$	212.64	35.44	5.25								
$CuGe_2P_3$	301.65	50.28	5.375		4.318	1113	8500	429	8.21	37.6	
$AgGe_2P_3$	345.97	57.66				1015	6150				

§A6. "Defect Chalcopyrite" Structure Compounds (Strukturbericht symbol E3, Space Group I $\bar{4}$-S_4^2)

$ZnAl_2Se_4$	435.18	62.17	5.503	10.90	4.37		
$ZnAl_2Te_4$(?)	629.74	84.96	5.904	12.05	4.95		
$ZnGa_2S_4$(?)	333.06	47.58	5.274	10.44	3.80		
$ZnGa_2Se_4$(?)	520.66	74.38	5.496	10.99	5.21		
$ZnGa_2Te_4$(?)	715.22	102.17	5.937	11.87	5.67		
$Znln_2Se_4$	610.86	87.27	5.711	11.42	5.44	1250	
$Znln_2Te_4$	805.42	115.06	6.122	12.24	5.83	1075	
$CdAl_2S_4$	294.61	42.09	5.564	10.32	3.06		
$CdAl_2Se_4$	482.21	68.89	5.747	10.68	4.54		
$CdAl_2Te_4$(?)	676.77	97.68	6.011	12.21	5.10		
$CdGa_2S_4$	380.09	54.30	5.577	10.08	4.03		
$CdGa_2Se_4$	567.69	81.10	5.743	10.73	5.32		
$CdGa_2Te_4$	762.25	108.89	6.093	11.81	5.77		
$Cdln_2Te_4$	852.45	121.78	6.205	12.41	5.9	1060	
$HgAl_2S_4$	382.79	54.68	5.488	10.26	4.11		
$HgAl_2Se_4$	570.39	82.48	5.708	10.74	5.05		
$HgAl_2Te_4$(?)	764.48	109.28	6.004	12.11	5.81		
$HgGa_2S_4$	468.27	66.90	5.507	10.23	5.00		
$HgGa_2Se_4$	655.87	93.70	5.715	10.78	6.18		
$Hgln_2Se_4$	746.07	106.58	5.764	11.80	6.3	1100	
$Hgln_2Te_4$(?)	940.63	134.38	6.186	12.37	6.3	980	

§A7. Other Adamantine Compounds

αSiC	40.1	20.1	3.0817		3.21	3070	
			15.1183				
$Hg_5Ga_2Te_8$	2163.19	144.21	6.235				
$Hg_5ln_2Te_8$	2253.39	150.23	6.328				
$Cdln_2Se_4$	657.89	93.98	a = c = 5.823				

Part B. Octahedral Semiconductors

§B1. Halite Structure Semiconductors (Strukturbericht symbol B1, Space Group Fm3m-O_h^5)

GeTe	200.19	100.1	5.98		6.14		
SnSe	197.65	98.83	6.020			1133	
SnTe	246.29	123.15	6.313		6.45	1080 (max)	91
Pbs	239.26	119.63	5.9362		7.61	1390	23
PbSe	286.16	143.08	6.1243		8.15	1340	17
PbTe	334.8	167.4	6.454		8.16	1180	23

Table I.
PHYSICO-CHEMICAL PROPERTIES OF SEMICONDUCTORS (LISTED BY CRYSTAL STRUCTURE) (continued)

Substance	Molecular Mass	Average Atomic Mass	Lattice Parameters (Å, Room Temp.)		Density (g/cm^3)	Melting Point (K)	Microhardness, N/mm^2 (M-Mohs Scale)	Specific Heat, J/kg·K (300 K)	Debye Temp. (K)	Coefficient of Thermal Linear Expansion [10^{-6} K^{-1} (300K)]	Thermal Conductivity [mW/cm·K (300K)]
Selected Other Binary Halites											
BiSe	287.94	143.97	5.99		7.98	880					
BiTe	336.58	168.29	6.47								
EuSe	230.92	115.46	6.191			2300					2.4
GdSe	236.21	118.11	5.771			2400					
NiD	60.71	30.35	4.1684		6.6	2260					
CdO	128.41	64.21	4.6953			1700					7
SrS	119.68	59.84	6.0199		3.643	3000					
Part C. Other Semiconductors											
§C1. Antifluorite Structure Compounds ($Fm3m–O_h^5$)											
Mg_2Si	76.70	25.57	6.338		1.88	1375				11.5	
Mg_2Ge	121.20	40.4	6.380		3.08	1388				15.0	
Mg_2Sn	167.3	55.77	6.765		3.53	1051				9.9	92
Mg_2Pb	225.81	85.27	6.836		5.1	823				10.0	
§C2. Tetradymite Structure Compounds ($\bar{R}3m–D_{3d}^5$)											
Sb_2Te_3	626.3	125.26	4.25	30.3	6.44	895					
Bi_2Se_3	654.84	130.97	4.14	28.7	7.51	979	167				24
Bi_2Te_3	800.76	160.15	4.38	30.45	7.73	858	155	16			30
§C3. Skutterudite Structure Compounds ($Im3–T_h^5$)											
CoP_3	151.85	37.96	7.7073			>1270					
$CoAs_3$	286.70	71.65	8.2060		6.73	1230					
$CoSb_3$	424.18	106.05	9.0385			1123			307		50
$NiAs_3$	283.45	70.86	8.330		6.43						
RhP_3	195.83	48.96	7.9951			>1470					
$RhAs_3$	327.67	81.92	8.4427			>1270					100

$RhSb_3$	468.16	117.04	9.2322		1170					
IrP_3	285.14	71.29	8.0151	7.36	>1470					
$IrAs_3$	416.98	104.25	8.4673	9.12	>1470					90
$IrSb_3$	557.47	139.37	9.2533	9.35	1170			303		
§C4. Selected Multinary Compounds										
$AgSbSe_2$	387.54	96.88	5.786	6.60	910					10.5
$AgSbTe_2$ (or $Ag_{19}Sb_{29}Te_{52}$)	484.82	121.2	6.078	7.12	830					86, 0.3
$AgBiS_2$(H.T.)	380.97	95.24	5.648							
$AgBiSe_2$(H.T.)	474.77	118.69	5.82							
$AgBiTe_2$(H.T.)	572.05	143.01	6.155							
Cu_2CdSnS_4	486.43	60.80	5.586	10.83						
§C5. Some Elemental Semiconductors										
β	10.81	4.91	12.6	2.34	2348	9.5 (M)	1277	1370	8.3	600
Se(gray)	78.96	4.36	4.95	4.81	493	350	292.6		(‖C) 17.89 (⊥C) 74.09	(‖C) 45.2 (⊥C) 13.1
Te	127.6	4.45	5.91	6.23	723		196.5		16.8	(‖C) 33.8 (⊥C) 19.7

Table II
Basic Thermodynamic, Electrical, and Magnetic Properties of Semiconductors (Listed by Crystal Structure)

Substance	Heat of Formation [kJ/mole (300K)]	Volume Compressibility ($10^{-10}m^2/N$)	Static Dielectric Constant	Atomic Magnetic Susceptibility (10^{-6} CGS)	Index of Refraction	Miniumum Room Temperature Energy Gap (eV)	Mobility (Room Temp.) ($cm^2/V{\cdot}s$) Electrons	Holes	Optical Transition	Remarks
Part A. Adamantine Semiconductors										
§Al. Diamond Structure Elements (Strukturbericht symbol A4, Space Group Fd 3m–O_h^7)										
C	714.4	18	5.7	–5.88	2.419 (589 nm)	5.4	1800	1400	i*	
Si	324	0.306	11.8	–3.9	3.49 (589 nm)	1.107	1900	500	i	
Ge	291	0.768	16	–012	3.99 (589 nm)	0.67	3800	1820	i	
α-Sn	267.5		24		2.75 (589 nm)	0.0; 0.8	2500	2400		

Table II
Basic Thermodynamic, Electrical, and Magnetic Properties of Semiconductors (Listed by Crystal Structure)

Substance	Heat of Formation [kJ/mole (300K)]	Volume Compressibility ($10^{-10}m^2/N$)	Static Dielectric Constant	Atomic Magnetic Susceptibility (10^{-6} CGS)	Index of Refraction	Miniumum Room Temperature Energy Gap (eV)	Mobility (Room Temp.) ($cm^2/V\cdot s$) Electrons	Holes	Optical Transition	Remarks
§A2. Sphalerite (Zinc Blende) Structure Compounds (Strukturbericht symbol B3 Space Group F $\bar{4}$ 3m–T_d^2)										
I VII Compounds										
CuF										
CuCl	481	0.26	7.9		1.93	3.17			d	Nantokite
CuBr	481	0.26	7.9		2.12	2.91			d	
Cul	439	0.27	6.5		2.346	2.95			d	Marshite
AgBr	486		12.4		2.253	2.50	4000		i	Bromirite
Agl	389	0.41	10		2.22	2.22	30		d	Miersite
II VI Compounds										
BeS					4.17				i	
BeSe					3.61				i	
BeTe					1.45		20		d	
BePo										
ZnO										See A3
ZnS	477		8.9	–9.9	2.356	3.54	180	5(400˚C)	d	See also A3
ZnSe	422		9.2		2.89	2.58	540	28	d	
ZnTe	376		10.4		3.56	2.26	340	100	d	
ZnP										
Cds										See A3
CdSe										See A3
CdTe	339		7.2		2.50	1.44	1200	50	d	
CdPo										
HgS					2.85		250		d	Metacinnabarite
HgSe	247					2.10 (α)	2000	≈1.5	s	Tiemannite
HgTe	242					–0.06	25000	350	s	Coloradoite
III V Compounds										
BN	815					4.6				Borazone
BP(L.T.)						≈2.1	500	70		Ignites 470K

BAs						≈1.5				
AlP						2.45	80		i	
AlAs	627		10.9			2.16	1200	420	i	
AlSb	585	0.571	11		3.2	1.60	200–400	550	i	
GaP	635	0.110	11.1	–13.8	3.2	2.24	300	150	i	
GaAs	535	0.771	13.2	–16.2	3.30	1.35	8800	400	d	
GaSb	493	0.457	15.7	–14.2	3.8	0.67	4000	1400	d	
InP	560	0.735	12.4	–22.8	3.1	1.27	4600	150	d	
InAs	477	0.549	14.6	–27.7	3.5	0.36	33000	460	d	
InSb	447	0.442	17.7	–32.9	3.96	0.163	78000	750	d	

* i = indirect, d = direct, s = semimetal.

Other sphalerite structure compounds										
MnS										See also §A3
MnSe										See also §A3
β-SiC					2.697	2.3	4000			
Ga_2Te_3	271			–13.5		1.35	50			
In_2Te_3(H.T.)	198			–13.6		1.04	50			
$MgGeP_2$										El–T[d12]
$ZnSnP_2$						2.1				Same
$ZnSnAs_2$(H.T.)						≈0.7				Same
$ZnSnSb_2$						0.4				Same

§A3. Wurtzite (Zincite) Structure Compounds (Strukturbericht symbol B4, Space Group P 6_3 mc-C^4_{6v})

I VII Compounds										
CuCl										
CuBr										
CuI										
AgI						2.63				Iodargirite
II VI Compounds										
BeO										
MgTe										
ZnO	–350					3.2	180			
ZnS	–206					3.67				
ZnTe	–163									
CdS			8.45; 9.12		2.32	2.42	350	40	d	Greenockide
CdSe						1.74	900	50	d	Cadmoselite
CdTe						1.50	650			

Table II
Basic Thermodynamic, Electrical, and Magnetic Properties of Semiconductors (Listed by Crystal Structure)

Substance	Heat of Formation [kJ/mole (300K)]	Volume Compressibility ($10^{-10}m^2/N$)	Static Dielectric Constant	Atomic Magnetic Susceptibility (10^{-6} CGS)	Index of Refraction	Miniumum Room Temperature Energy Gap (eV)	Mobility (Room Temp.) ($cm^2/V{\cdot}s$)		Optical Transition	Remarks
							Electrons	Holes		
III V Compounds										
BP(H.T.)										
AlN						6.02				
GaN						3.34				
lnN						2.0				
Other wurtzite structure compounds										
MnS										
MnSe										
SiC					2.654					
MnTe						≈1.0				
Al_2S_3	426					4.1				
Al_2Se_3	367					3.1				

§A4. Chalcopyrite Structure Compounds (Strukturbericht symbol $E1_1$, Space Group I $\bar{4}$ 2d-D^{12}_{2d})

Substance	Heat of Formation [kJ/mole (300K)]	Volume Compressibility ($10^{-10}m^2/N$)	Static Dielectric Constant	Atomic Magnetic Susceptibility (10^{-6} CGS)	Index of Refraction	Miniumum Room Temperature Energy Gap (eV)	Electrons	Holes	Optical Transition	Remarks
I III VI_2 Compounds										
$CuAlS_2$		0.106				2.5				
$CuAlSe_2$						1.1				
$CuAlTe_2$						0.88				
$CuCaS_2$		0.106				2.38				
$CuGaSe_2$		0.141				0.96, 1.63				
$CuGaTe_2$		0.227				0.82, 1.0				
$CulnS_2$		0.141				1.2				
$CulnSe_2$		0.187				0.86, 0.92				
$CulnTe_2$		0.278				0.95				
$CuTlS_2$										
$CuTlSe_2$(L.T.)						1.07				
$CuFeS_2$						0.53				Chalcopyrite
$CuFeSe_2$						0.16				
$CuLaS_2$										
$AgAlS_2$										

$AgAlSe_2$					0.7			
$AgAlTe_2$					0.56			
$AgGaS_2$		0.150			1.66			
$AgGaSe_2$		0.182			1.1			
$AgGaTe_2$		0.280			1.9			
$AgInS_2$(L.T.)		0.185			1.18			
$AgInSe_2$		0.238			0.96, 0.52			
$AgInTe_2$		0.338						
$AgFeS_2$								
V V_2 Compounds								
$ZnSiP_2$	312				2.3	1000		
$ZnGeP_2$	293				2.2			
$ZnSnP_2$	275				1.45			
$CdSiP_2$		0.103			2.2	1000		
$CdGeP_2$	289				1.8			
$CdSnP_2$	270				1.5			
$ZnSiAs_2$	290				1.7		50	
$ZnGeAs_2$	271			–14.4	0.85			
$ZnSnAs_2$	252			–18.4	0.65		300	Disorders at 910K
$CdSiAs_2$		0.143			1.6			
$CdGeAs_2$	266			–23.4	0.53	70	25	Disorders at 903
$CdSnAs_2$	247		13.7	–21.5	0.26	22000	250	

§A5. Other Ternary Semiconductors with Tetrahedral Coordination

IV VI_3 Compounds								
Cu_2SiS_3(H.T.)								Wurtzite
Cu_2SiS_3(L.T.)								Tetragonal
Cu_2SiTe_3								Cubic
Cu_2GeS_3(H.T.)				–18.7				Cubic
Cu_2GeS_3(L.T.)						360		Tetragonal
Cu_2GeSe_3	211.5			–21.3	0.94	238		Same
Cu_2GeTe_3	190.2			–23.4				Same
Cu_2SnS_3				–18.2	0.91	405		Cubic
$CuSnSe_3$				–21.0	0.66	870		Cubic
Cu_2SnTe_3				–28.4				Cubic
Ag_2GeSe_3				–29.6	0.91 (77K)			
Ag_2SnSe_3				–29.5	0.81			
Ag_2GeTe_3				–31.4	0.25			
Ag_2SnTe_3				–31.10	0.08			

Table II
Basic Thermodynamic, Electrical, and Magnetic Properties of Semiconductors (Listed by Crystal Structure)

Substance	Heat of Formation [kJ/mole (300K)]	Volume Compressibility ($10^{-10}m^2/N$)	Static Dielectric Constant	Atomic Magnetic Susceptibility (10^{-6} CGS)	Index of Refraction	Miniumum Room Temperature Energy Gap (eV)	Mobility (Room Temp.) ($cm^2/V{\cdot}s$) Electrons	Holes	Optical Transition	Remarks
V VI_4 Compounds										
Cu_3PS_4										Enargite
Cu_3AsS_4	269.6			–15.8		1.24				
Cu_3AsSe_4	161.3			–13.1		0.88				Famatinite
Cu_3SbS_4				–8.3		0.74				Famatinite
Cu_3SbSe_4	127.1			–20.5		0.31				
V_2 V_3 Compounds										
$CuSi_2P_3$										El
$CuGe_2P_3$		0.12				0.90				El
$AgGe_2P_3$										
§A6. "Defect Chalcopyrite" Structure Compounds (Strukturbericht symbol E3, Space Group I $\bar{4}$-S_4^2)										
$ZnAl_2Se_4$										
$ZnAl_2Te_4$(?)										
$ZnGa_2S_4$(?)						≈3.4				
$ZnGa_2Se_4$(?)						≈2.2				
$ZnGa_2Te_4$(?)						1.35				
$ZnIn_2Se_4$	206					1.82	35			
$ZnIn_2Te_4$	198					1.2				
$CdAl_2S_4$										
$CdAl_2Se_4$										
$CdAl_2Te_4$(?)										
$CdGa_2S_4$	256					3.44	60			
$CdGa_2Se_4$	216					2.43	33			
$CdGa_2Te_4$										
$CdIn_2Te_4$	195					(1.26 or 0.9)	4000			
$HgAl_2S_4$										
$HgAl_2Se_4$										

$HgAl_2Te_4$(?)									
$HgGa_2S_4$	249					2.84			
$HgGa_2Se_4$	204					1.95	400		
$HgIn_2Se_4$	196					0.6	290		
$HgIn_2Te_4$(?)	188					0.86	200		

§A7. Other Adamantine Compounds

αSiC		10.2	–6.4	2.67	2.86	400			6H structure
$Hg_5Ga_2Te_8$									B3 with superlattice
$Hg_5In_2Te_8$					0.7	2000			B3 with superlattice
$CdIn_2Se_4$					1.55				

Part B. Octahedral Semiconductors

§B1. Halite Structure Semiconductors (Strukturbericht symbol B1, Space Group Fm3m-O_h^5)

GeTe									
SnSe									
SnTe									
PbS	435					0.5	600	600	
PbSe	393		161			0.37	1000	900	
PbTe	393		280			0.26	1600	600	Altaite
			360			0.25			
Selected Other Binary Halites									
BiSe									
BiTe						0.4			
EuSe									
GdSe						1.8	4		
NiD						2.0 or 3.7	100		
CdO	531					2.5			
SrSW						4.1			

Part C. Other Semiconductors

§C1. Antifluorite Structure Compounds (Fm3m-O_h^5)

Mg_2Si	79.08					0.77	405	70	
Mg_2Ge						0.74	520	110	
Mg_2Sn	76.57					0.36	320	260	
Mg_2Pb	52.72					0.1			

Table II
Basic Thermodynamic, Electrical, and Magnetic Properties of Semiconductors (Listed by Crystal Structure)

Substance	Heat of Formation [kJ/mole (300K)]	Volume Compressibility ($10^{-10}m^2/N$)	Static Dielectric Constant	Atomic Magnetic Susceptibility (10^{-6} CGS)	Index of Refraction	Miniumum Room Temperature Energy Gap (eV)	Mobility (Room Temp.) ($cm^2/V\cdot s$) Electrons	Holes	Optical Transition	Remarks
§C2. Tetradymite Structure Compounds ($R\bar{3}m\text{-}D^5_{3d}$)										
Sb_2Te_3						0.3		360		
Bi_2Se_3						0.35	600			
Bi_2Te_3						0.21	1140	680		R3m (166)
§C3. Skutterudite Structure Compounds ($Im3\text{-}T^5_h$)										
CoP_3						0.43				
$CoAs_3$						0.69		–4000		
$CoSb_3$						0.63	70	–3000		
RhP_3								700		
$RhAs_3$						0.85		–3000		
$RhSb_3$						0.80		–7000		
$IrSb_3$						1.18		1500		
§C4. Selected Multinary Compounds										
$AgSbSe_2$						0.58				
$AgSbTe_2$ (or $Ag_{19}Sb_{29}Te_{52}$)						0.7, 0.27				
$AgBiS_2$(H.T.)										
$AgBiSe_2$(H.T.)										
$AgBiTe_2$(H.T.)										
Cu_2CdSnS_4						1.16	<2			
§C5. Some Elemental Semiconductors										
B	397.1			–6.7	3.4	1.55	10			
Se(gray)			6.6 (0.1 GHz)	–22.1	2.5	1.5		5		$P3_121(152)$
Te				–39.5	3.3	0.33	1700	1200		Same

Table III
Semiconducting Properties of Selected Materials

Substance	Minimum Energy Gap (eV)		$dE_g/dT \times 10^4$ cV/°C	$dE_g/dP \times 10^6$ cV·cm²/kg	Density of States Electron Effective Mass m_{da} (m_o)	Electron Mobility and Temperature Dependence		Density of States Hole Effective Mass m_{dp} (m_n)	Role Mobility and Temperature Dependence	
	R.T.	0 K				μ_n cm²/V·s	–x		μ_p cm²/V·s	–x
Si	1.107	1.153	–2.3	–2.0	1.1	1900	2.6	0.56	500	2.3
Ge	0.67	0.744	–3.7	+7.3	0.55	3800	1.66	0.3	1820	2.33
αSn	0.08	0.094	–0.5		0.02	2500	1.65	0.3	2400	2.0
Te	0.33				0.08	1100		0.19	560	
III-V Compounds										
AlAs	2.2	2.3				1200			420	
AlSb	1.6	1.7	–3.5	–1.6	0.09	200	1.5	0.4	500	1.8
GaP	2.24	2.40	–5.4	–1.17	0.35	300	1.5	0.5	150	1.5
GaAs	1.35	1.53	–5.0	+9.4	0.068	9000	1.0	0.5	500	2.1
GaSb	0.67	0.78	–3.5	+12	0.050	5000	2.0	0.23	1400	0.9
InP	1.27	1.41	–4.6	+4.6	0.067	5000	2.0		200	2.4
InAs	0.36	0.43	2.8	+8	0.022	33,000	1.2	0.41	460	2.3
InSb	0.165	0.23	–2.8	+15	0.014	78,000	1.6	0.4	750	2.1
II-VI Compounds										
Zn()	3.2		–0.5	+0.6	0.38	180	1.5			
ZnS	3.54		–5.3	+5.7		180			5(400°C)	
ZnSe	2.58	2.80	–7.2	+6		540			28	
ZnTe	2.26			+6		340			100	
CdO	2.5 ± .1		–6		0.1	120				
CdS	2.4		–5	+3.3	0.165	400		0.8		
CdSe	1.74	1.85	–4.6		0.13	650	1.0	0.6		
GdTe	1.44	1.56	–4.1	+8	0.14	1200		0.35	50	
HgSe	0.30				0.030	20,000	2.0			
HgTe	0.15		–1		0.017	25,000		0.5	350	
Halite Structure Compounds										
PbS	0.37	0.28	+4		0.16	800		0.1	1000	2.2
PbSe	0.26	0.16	+4		0.3	1500		0.34	1500	2.2
PbTe	0.25	0.19	+4	–7	0.21	1600		0.14	750	2.2

Properties of Semiconductors (continued)

Table III
Semiconducting Properties of Selected Materials

Substance	Minimum Energy Gap (eV) R.T.	Minimum Energy Gap (eV) 0 K	$dE_g/dT \times 10^4$ cV/°C	$dE_g/dP \times 10^6$ cV·cm²/kg	Density of States Electron Effective Mass m_{da} (m_o)	Electron Mobility and Temperature Dependence μ_n cm²/V·s	Electron Mobility and Temperature Dependence –x	Density of States Hole Effective Mass m_{dp} (m_n)	Role Mobility and Temperature Dependence μ_p cm²/V·s	Role Mobility and Temperature Dependence –x
Others										
ZnSb	0.50	0.56			0.15	10				1.5
CdSb	0.45	0.57	–5.4		0.15	300			2000	1.5
Bi_2S_3	1.3					200			1100	
Bi_2Se_3	0.27					600			675	
Bi_2Te_3	0.13		–0.05		0.58	1200	1.68	1.07	510	1.95
Mg_2Si		0.77	–6.4		0.46	400	2.5		70	
Mg_2Ge		0.74	–9			280	2		110	
Mg_2Sn	0.21	0.33	–3.5		0.37	320			260	
Mg_3Sb_2		0.32				20			82	
Zn_3As_2	0.93					10	1.1		10	
Cd_3As_2	0.55				0.046	100,000	0.88			
GaSe	2.05		3.8						20	
GaTe	1.66	1.80	–3.6			14	–5			
InSe	1.8					900				
TlSe	0.57		–3.9		0.3	30		0.6	20	1.5
$CdSnAs_2$	0.23				0.05	25,000	1.7			
Ga_2Te_2	1.1	1.55	–4.8							
α-ln_2Te_2	1.1	1.2			0.7				50	1.1
β-ln_2Te_2	1.0								5	
$Hg_5ln_2Te_8$	0.5								11,000	
SnO_2									78	

Table IV
Band Properties of Semiconductors

Part A. Data on Valence Bands of Semiconductors (Room Temperatures)

Substance	Band Curvature Effective Mass (Expressed as Fraction of Free Electron Mass)			Energy Separation of "Split-Off" Band (eV)	Measured (Light) Hole Mobility $cm^2/V{\cdot}s$
	Heavy Holes	Light Holes	"Split-Off" Band Boles		
Semiconductors with Valence Band Maximum at the Center of the Brillouin Zone ("F")					
Si	0.52	0.16	0.25	0.044	500
Ge	0.34	0.043	0.08	0.3	1820
Sn	0.3				2400
AlAs					
AlSb	0.4			0.7	550
GaP				0.13	100
GaAs	0.8	0.12	0.20	0.34	400
GaSb	0.23	0.06		0.7	1400
InP				0.21	150
InAs	0.41	0.025	0.083	0.43	460
InSb	0.4	0.015		0.85	750
CdTe	0.35				50
HgTe	0.5				350

Semiconductors with Multiple Band Maxima

Substance	Number of Equivalent Valleys and Direction	Band Curvature Effective Masses		Anistrophy $K = m_L/m_T$	Measured (Light) Hole Mobility $cm^2/V{\cdot}s$
		Longitudinal m_L	Transverse m_T		
PbSe	4 "L" [111]	0.095	0.047	2.0	1500
PbTe	4 "L" [111]	0.27	0.02	10	750
Bi_2Te_3	6	0.207	~0.045	4.5	515

Properties of Semiconductors (continued)

Table IV
Band Properties of Semiconductors

Part B. Data on Conduction Bands of Semiconductors (Room temperature Data)

Single Valley Semiconductors

Substance	Energy Gap (eV)	Effective Mass (m_o)	Mobility ($cm^2/V{\cdot}s$)	Comments
GaAs	1.35	0.067	8500	3(or 6?) equivalent [100] valleys 0.36 eV above this maximum with a mobility of ~50
InP	1.27	0.067	5000	3(or 6?) equivalent [100] valleys 0.4 eV above this minimum.
InAs	0.36	0.022	33,000	Equivalent valleys ~1.0 eV above this minimum.
InSb	0.165	0.014	78,000	
CdTe	1.44	0.11	1000	4(or 8?) equivalent [111] valleys 0.51 eV above this minimum.

Multivalley Semiconductors

Substance	Energy Gap	Number of Equivalent Valleys and Direction	Band Curvature Effective Mass: Longitudinal m_L	Band Curvature Effective Mass: Transverse m_T	Anisotropy $K = m_L/m_T$	Comments
Si	1.107	6 in [100] "Δ"	0.00	0.192	4.7	
Ge	0.6	4 in [111] at "L"	1.588	0.0815	19.5	
GaSb	0.67	as Ge (?)	~1.0	~0.2	~5	
PbSe	0.26	4 in [111] at "L"	0.085	0.05	1.7	
PbTe	0.25	4 in [111] at "L"	0.21	0.029	5.5	
Bi_2Te_2	0.13	6			~0.05	

Table V
Resistivity of Semiconducting Minerals

Mineral	ρ (ohm · m)	Mineral	ρ (ohm · m)
Diamond (C)	2.7	Gersdorfite, $NiAsS$	1 to 160×10^{-6}
Sulfides		Glaucodote, $(Co, Fe)AsS$	5 to 100×10^{-6}
Argentite, Ag_2S	1.5 to 2.0×10^{-3}	Antimonide	
Bismuthinite, Bi_2S_3	3 to 570	Dyscrasite, Ag_3Sb	0.12 to 1.2×10^{-6}
Bornite, $Fe_2S_3 \cdot nCu_3S$	1.6 to 6000×10^{-4}	Arsenides	
Chalcocite, Cu_2S	80 to 100×10^{-6}	Allemonite, $SbAs_1$	70 to 60,000
Chalcopyrite, $Fe_2S_1 \cdot Cu_1S$	150 to 9000×10^{-6}	Lollingite, $FeAs_2$	2 to 270×10^{-6}
Covellite, CuS	0.30 to 83×10^{-6}	Nicollite, $NiAs$	0.1 to 2×10^{-6}
Galena, PbS	6.8×10^{-6} to 9.0×10^{-2}	Skutterudite, $CoAs_3$	1 to 400×10^{-6}
Haverite, MnS_2	10 to 20	Smaltite, $CoAs_2$	1 to 12×10^{-6}
Marcasite, FeS_2	1 to 150×10^{-2}	Tellurides	
Metacinnabarite, $4HgS$	2×10^{-6} to 1×10^{-3}	Altaite, $PbTe$	20 to 200×10^{-6}
Millerite, NiS	2 to 4×10^{-7}	Calavarite, $AuTe_2$	6 to 12×10^{-6}
Molybdenite, MoS_2	0.12 to 7.5	Coloradoite, $HgTe$	4 to 100×10^{-6}
Pentlandite, $(Fe, Ni)_4S_4$	1 to 11×10^{-6}	Hessite, Ag_2Te	4 to 100×10^{-6}
Pyrrhotite, Fe_7S_4	2 to 160×10^{-6}	Nagyagite, $Pb_6Au(S,Te)_{14}$	20 to 80×10^{-6}
Pyrite, FeS_2	1.2 to 600×10^{-3}	Sylvanite, $AgAuTe_4$	4 to 20×10^{-6}
Sphalerite, ZnS	2.7×10^{-2} to 1.2×10^{4}	Oxides	
Antimony-sulfur compounds		Braunite, Mn_2O_1	0.16 to 1.0
Berthierite, $FeSb_2S_4$	0.0083 to 2.0	Cassiterite, SnO_3	4.5×10^{-4} to 10,000
Boulangerite, $Pb_5Sb_3S_{11}$	2×10^{3} to 4×10^{4}	Cuprite, Cu_2O	10 to 50
Cylindrite, $Pb_3Sn_4Sb_2S_{14}$	2.5 to 60	Hollandite, $(Ba, Na, K)\ Mn_8O_{16}$	2 to 100×10^{-3}
Franckeite, $Pb_5Sn_1Sb_2S_{14}$	1.2 to 4	Ilmenite, $FeTiO_1$	0.001 to 4
Hauchecornite, $Ni_4(Bi, Sb)_2S_4$	1 to 83×10^{-6}	Magnetite, Fe_1O_4	52×10^{-6}
Jamesonite, $Pb_4FeSb_6S_{14}$	0.020 to 0.15	Manganite, $MnO \cdot OH$	0.018 to 0.5
Tetrahedrite, Cu_3SbS_3	0.30 to 30,000	Melaconite, CuO	6000
Arsenic-sulfur compounds		Psilomelane, $KMnO \cdot MnO_1 \cdot nH_2O$	0.04 to 6000
Arsenopyrite, $FeAsS$	20 to 300×10^{-6}	Pyrolusite, MnO_2	0.007 to 30
Cobaltite, $CoAsS$	6.5 to 130×10^{-3}	Rutile, TiO_2	29 to 910
Enargite, Cu_3AsS_4	0.2 to 40×10^{-3}	Uraninite, UO	1.5 to 200

References

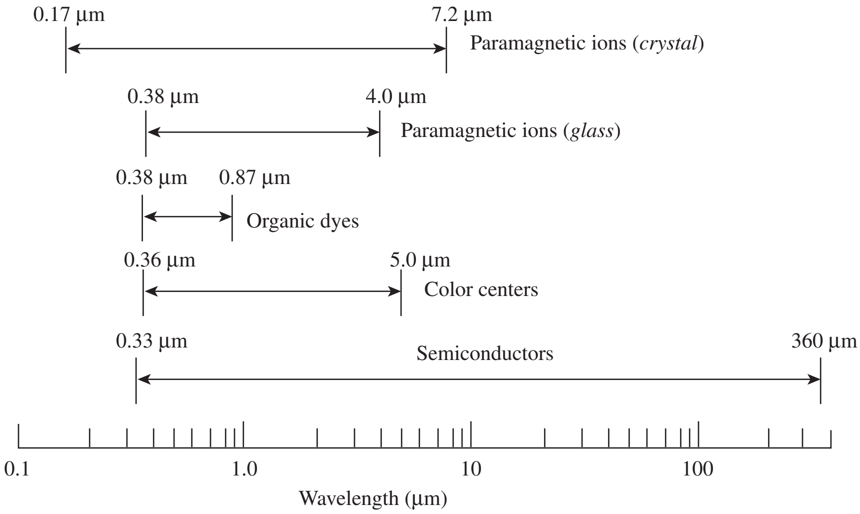
1. Beer, A.C., *Galvanomagnetic Effects in Semiconductors*, Academic Press, 1963.
2. Goryunova, N.A., *The Chemistry of Diamond-Like Semiconductors*, The MIT Press, 1965.
3. Abrikosov, N. Kh., Bankina, V.F., Poretskaya, L.E., Shelimova, L.E., and Skudnova, E.V., *Semiconducting II-VI, IV-VI, and V-VI Compounds*, Plenum Press, 1969.
4. Berger, L.I. and Prochukhan, V.D., *Ternary Diamond-Like Semiconductors*, Cons. Bureau/Plenum Press, 1969.
5. Shay, J.L. and Wernick, J.H., *Ternary Chalcopyrite Semiconductors: Growth, Electronic Properties, and Applications*, Pergammon Press, 1975.
6. Bergman, R., *Thermal Conductivity in Solids*, Clarendon, Oxford, 1976.
7. Handbook of Semiconductors, Vol. 1, Moss, T.S. and Paul, W., Eds., *Band Theory and Transport Properties*; Vol. 2, Moss, T.S. and Balkanski, M., Eds., *Optical Properties of Solids*; Vol. 3, Moss, T.S. and Keller, S.P., Eds., *Materials Properties and Preparation*, North Holland Publ. Co., 1980.
8. Böer, K.W., *Survey of Semiconductor Physics*, Van Nostrand Reinhold, 1990.
9. Rowe, D.M., Ed., *CRC Handbook of Thermoelectrics*, CRC Press, Boca Raton, FL, 1995.
10. Berger, L.I., *Semiconductor Materials*, CRC Press, Boca Raton, FL, 1997.
11. Glazov, V.M., Chizhevskaya, S.N., and Glagoleva, N.N., *Liquid Semiconductors*, Plenum Press, New York, 1969.
12. Phillips, J.C., *Bonds and Bands in Semiconductors*, Academic Press, New York, 1973.
13. Harrison, W.A., *Electronic Structure and the Properties of Solids*, Freeman Publ. House, San Francisco, 1980.
14. Balkanski, M., Ed., *Optical Properties of Solids*, North-Holland, Amsterdam, 1980.
15. *Landolt-Börnstein. Numerical Data and Functional Relationships in Science and Technology, New Series, Group III: Crystal and Solid State Physics*, Hellwege, K.-H. and Madelung, O., Eds., Volumes 17 and 22, Springer Verlag, Berlin, 1984 (and further).
16. Shklovskii, B.L. and Efros, A.L., *Electronic Processes in Doped Semiconductors*, Springer Verlag, Berlin, 1984.
17. Cohen, M.L. and Chelikowsky, J.R., *Electronic Structure and Optical Properties of Semiconductors*, Springer Verlag, New York, 1988.
18. Glass, J.T., Messier, R.F., and Fujimori, N., Eds., *Diamond, Silicon Carbide, and Related Wide Bandgap Semiconductors*, MRS Symposia Proc. 1652, Mater. Res. Soc., Pittsburgh, 1990.
19. Palik, E., Ed., *Handbook of Optical Constants of Solids II*, Academic Press, New York, 1991.
20. Reed, M., Ed., *Semiconductors and Semimetals*, Volume 35, Academic Press, Boston, 1992.
21. Haug, H. and Koch, S.W., *Quantum Theory of the Optical and Electronic Properties of Semiconductors*, 2nd Edition, World Scientific, Singapore, 1993.
22. Lockwood, D.J., Ed., *Proc. 22nd Intl. Conf. on the Physics of Semiconductors, Vancouver, 1994*, World Scientific, Singapore, 1994.
23. Morelli, D.T., Caillat, T., Fleurial, J.-P., Borschchevsky, A., Vandersande, J., Chen, B., and Uher, C., *Phys. Rev.*, B51, 9622, 1995.
24. Caillat, T., Borshchevsky, A., and Fleurial, J.-P., *J. Appl. Phys.*, 80, 4442, 1996.
25. Fleurial, J.-P.,Caillat, T., and Borshchevsky, A., *Proc. XVI Intl. Conf. Thermoelectrics*, Dresden, Germany, August 26–29, 1997 (in print).
26. Borshchevsky, A. et al., U.S. Patents 5,610,366 (March 1977) and 5,831,286 (March 1998).

From Berger, L.I. and Pamplin, B.R., Properties of semiconductors, in *CRC Handbook of Chemistry and Physics*, 83rd ed., Lide, D., Ed., CRC Press, Boca Raton, FL, 2002, pp. **12**-97 to **12**-107. Originally from Carmichael, R.S., ed., *Handbook of Physical Properties of Rocks,* Vol. I, CRC Press, 1982.

Solid State Lasers

Solid state lasers include lasers based on paramagnetic ions, organic dye molecules, and color centers in crystalline or amorphous hosts. Semiconductor lasers are included in this section because they are a solid-state device, although the nature of the active center—recombination of electrons and holes—is different from the dopants or defect centers used in other lasers in this category. Conjugated polymer lasers, solid-state excimer lasers, and fiber raman, Brillouin, and soliton lasers are also covered in this section.

Reported ranges of output wavelengths for the various types of solid state lasers are shown in the figure. The differences in the ranges of spectral coverage arise in part from the dependence on host properties, in particular the range of transparency and the rate of nonradiative decay due to multiphonon processes.



Reported ranges of output wavelengths for various types of solid state lasers.

Further Reading

Cheo, P.K., Ed., *Handbook of Solid-State Lasers*, Marcel Dekker Inc., New York (1989).

Koechner, W., *Solid-State Laser Engineering* (fourth edition), Springer-Verlag, Berlin (1996).

Powell, R.C., *Physics of Solid State Laser Materials,* Springer-Verlag, Berlin (1997).

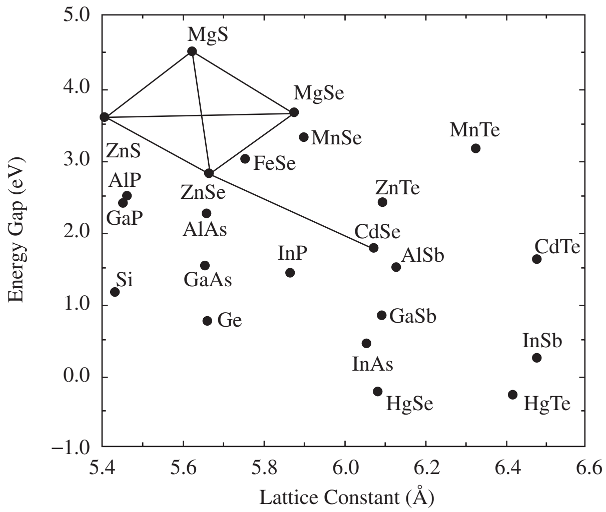
Powell, R.C., Ed., *Selected Papers on Solid State Lasers*, SPIE Milestone Series, Vol. MS31, SPIE Optical Engineering Press, Bellingham, WA (1991).

From Weber, M.J., Solid state lasers, in *Handbook of Lasers*, CRC Press, Boca Raton, FL, 2001.

III-V Material Systems with Important Optoelectronic Applications

Material System	Substrate	Lattice-Matched Members	Important Strained Members	Main Optoelectronic Applications
AlGaAs	GaAs	GaAs $Al_xGa_{1-x}As$ $0 \le x \le 1$ AlAs	$Ga_{1-x}In_xAs$ $0 \le x \le 0.25$	Emitters and modulators: $0.75\ \mu m \le \lambda \le 1.1\ \mu m$, Detectors: $0.4\ \mu m \le \lambda \le 1.1\ \mu m$ Saturable absorbers: $\lambda \sim 0.8–0.9\ \mu m$
GaInAsP/InP	InP	$Ga_{0.47}In_{0.53}As$ $Ga_xIn_{1-x}AsyP_{1-y}$ $x = 0.47\ y$; $0 \le y \le 1$ InP	$Ga_{1-x}In_xAs$ $0.4 \le x \le 0.6$ $InAs_xP_{1-x}$ $0 \le x \le 0.2$	Optoelectronic devices at $\lambda = 1.3\ \mu m$ and $1.55\ \mu m$
AlGaInAs/InP	InP	$Ga_{0.47}In_{0.53}As$ $(Al_xGa_{1-x})_{0.47}In_{0.53}As$ $0 \le x \le 1$ $Al_{0.48}In_{0.52}As$	$Ga_{1-x}In_xAs$ $0.4 \le x \le 0.6$	Optoelectronic devices at λ $= 1.3\ \mu m$ and $1.55\ \mu m$
AlGaInP	GaAs	GaAs $Ga_{0.5}In_{0.5}P$ $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ $0 \le x \le 1$ $Al_{0.5}In_{0.5}P$	$Ga_{1-x}In_xAs$ $0 \le x \le 0.25$ $Ga_{1-x}In_xP$ $0.4 \le x \le 0.6$	Red emitters
AlGaAsSb/ GaInAsSb/ GaSb	GaSb	GaSb $Al_xGa_{1-x}As_ysb_{1-y}$ $x = 12\ y$; $0 \le x \le 1$ $Ga_{1-x}In_xAs_{1-y}Sb_y$ $x = 1.1\ y$; $0 \le x \le 1$		Emitters and detectors: $\lambda \sim 2\text{-}3\ \mu m$
GaAsP	GaAs or GaP	GaAs (on GaAs substrates); GaP (on GaP substrates)	GaAsP	Visible LED's

From Wicks, G.W., III-V Semiconductor materials, in *Handbook of Photonics*, Gupta, M.C., Ed., CRC Press, Boca Raton, FL, 1997, p. 6.



Energy Gap and lattice parameters for cubic group IV, III-V and II-VI semiconductors. (From Luo, H. and Petrou, A., Optical properties and optoelectronic applications of II-VI semiconductor heterostructures, in *Handbook of Photonics*, Gupta, M.C., Ed., CRC Press, Boca Raton, FL, 1997, p. 26.)

Important Parameters of Semiconductors of Interest for Conventional Electronics and Emerging High Temperature Electronics

Property	Si	GaAs	GaP	3C SiC (6H SiC)	Diamond	GaN
Bandgap (eV) at 300K	1.1	1.4	2.3	2.2 (2.9)	5.5	3.39
Maximum operating temperature (K)	600?	760?	1250?	1200 (1580) sublimes	1400(?) phase change	
Melting point (K)	1690	1510	1740	>2100		
Physical stability	Good	Fair	Fair	Excellent	Very good	Good
Electron mobility R.T., cm^2/V-s	1400	8500	350	1000 (600)	2200	900
Hole mobility R.T., cm^2/V-s	600	400	100	40	1600	50?
Breakdown voltage E_b, 10^6/V/cm	0.3	0.4	—	4	10	5?
Thermal conductivity K, W/cm-C	1.5	0.5	0.8	5	20	1.3
Sat. elec. drift vel. v(sat), 10^7 cm/s	1	2	—	2	2.7	2.7
Dielectric const, K	11.8	12.8	11.1	9.7	3.5	9

From Morkoc, H., GaN and silicon carbide as optoelectronic materials, in *Handbook of Photonics*, Gupta, M.C., Ed., CRC Press, Boca Raton, FL, 1997, p. 52.

Properties of GaN(a), AIN(b), and InN(c)

Wurtzite Polytype		
Bandgap energy	E_g (300K) = 3.39 eV	E_g (1.6K) = 3.50 eV
Temperature coefficient	$\frac{dE_g}{dT} = 6.0 \times 10^{-4}$ eV/K	
Pressure coefficient	$\frac{dE_g}{dP} = 4.2 \times 10^{-3}$ eV/kbar	
Lattice constants	a = 3.189 ≈ Å	
Thermal expansion	$\frac{\Delta a}{a} = 5.59 \times 10^{-6}$/K	$\frac{\Delta c}{c} = 3.17 \times 10^{-6}$/K
Thermal conductivity	κ = 1.3 W/cmK	
Index of refraction	n(1 eV) = 2.33	n(3.38 eV) = 2.67
Dielectric constants	$\epsilon_r \approx 9$	$\epsilon_\infty = 5.35$
Zincblende Polytype		
Bandgap energy	E_g (300K) = 3.2–3.3 eV	
Lattice constant	a = 4.52 Å	
Index of refraction	n(3 eV) = 2.5	
Bandgap energy	E_g (300K) = 6.2 eV	E_g (5K) = 6.28 eV
Lattice constants	a = 3.112 Å, c = 4.982 Å	
Thermal expansion	$\frac{\Delta a}{a} = 4.2 \times 10^{-6}$/K	$\frac{\Delta c}{c} = 5.3 \times 10^{-6}$/K
Thermal conductivity	κ = 2\W/cmK	
Index of refraction	n(3eV) = 2.15 ± 0.05	
Dielectric constants	$\epsilon_r \approx 8.5 \pm 0.2$	ϵ_∞ = 4.68–4.84
Zincblende Polytype		
Bandgap energy	E_g (300K) = 5.11 eV, theory	
Lattice constant	a = 4.38 Å	
Bandgap energy	E_g (300K) = 1.89 eV	
Temperature coefficient	$\frac{dE_g}{dT} = 1.8 \times 10^{-4}$ eV/K	
Lattice constants	a = 3.5438 Å	c = 5.760 Å
Index of refraction	n = 2.80–3.05	
Dielectric constants	$\epsilon_r \approx$	
Zincblende Polytype		
Bandgap energy	E_g (300K) = 2.2 eV, theory	
Lattice constant	a = 4.98 Å	

From Morkoc, H., GaN and silicon carbide as optoelectronic materials, in *Handbook of Photonics*, Gupta, M.C., Ed., CRC Press, Boca Raton, FL, 1997, p. 65.

List of Ferroelectric Materials and Their Crystal Growth Methods

Family	Ferroelectric Material	Chemical Formula	Abbrev.	Growth Method
Perovskite type	Barium titanate	$BaTiO_3$	—	Remeika method Top seed pulling method
	Potassium niobate	$KNbO_3$	—	Spontaneous nucleation and slow cooling Top seed solution growth Kyropoulos pulling
	Potassium tantalate	$KTaO_3$	—	The same as $KNbO_3$
	Potassium tantalate niobate	$KTa_{1-x}Nb_xO_3$	KTN	Kyropoulos technique Top seed solution growth
	Lead Ianthanum zirconate titanate (in the form of ceramics)	$Pb_{1-x}(Zr_yTi_{1-y})_{1-0.25x}V^B_{0.25x}O_3$	PLZT	Chemical coprecipitation of powder and subsequent hot-pressing in oxygen environment
Lithium niobate family	Lithium niobate	$LiNbO_3$	—	Czochralski's technique
	Lithium tantalate	$LiTaO_3$	—	Czochralski's technique
Tungsten-bronzetype	Barium strontium niobate	$Ba_{5x}Sr_{5(1-x)}Nb_{10}O_{30}$	SBN	Czochralski's method
	Barium sodium niobate	$Ba_{5x}Na_{5(1-x)}Nb_{10}O_{30}$	BNN	Czochralski's method
	Potassium lithium niobate	$K_3Li_2Nb_5O_{15}$	KLN	Kyropoulos method
	Potassium sodium strontium niobate	$(K_xNa_{1-x})_{0.4}(Sr_yBa_{1-y})_{0.8}Nb_2O_6$	KNSBN	Czochralski's technique
KDP family	Potassium dihydrogen phosphate	KH_2PO_4	KDP	Water solution temperature reduction method
	Potassium dihydrogen arsenate	KH_2AsO_4	KDA	The same as KDP
	Rubidium dihydrogen phosphate	RbH_2PO_4	RDP	The same as KDP
TGS type	Triglycine sulphate	$(NH_2CH_2COOH)_3 \cdot H_2SO_4$	TGS	Temperature reduction method
	Triglycine selenate	$(NH_2CH_2COOH)_3 \cdot H_2S_eO_4$	TGSe	The same as TGS
KTP family	Potassium titanyl phosphate	$KTiOPO_4$	KTP	Top seed flux growth
Bismuth titanate	Bismuth titanate	$Bi_4Ti_3O_{12}$	—	Flux-growth method
Rare earth molybdate	Gadolinium molybdate	β-$Gd_2(MoO)_3$	GMO	Pulling from melt
Lead germanium oxide	Lead germanium oxide	$5PbO \cdot 3GeO_2$, or $Pb_5Ge_3O_{11}$	—	Czochralski's technique Bridgman's technique
Antimony sulphoiodide	Antimony sulphoiodide	SbSI		Vapor phase growth

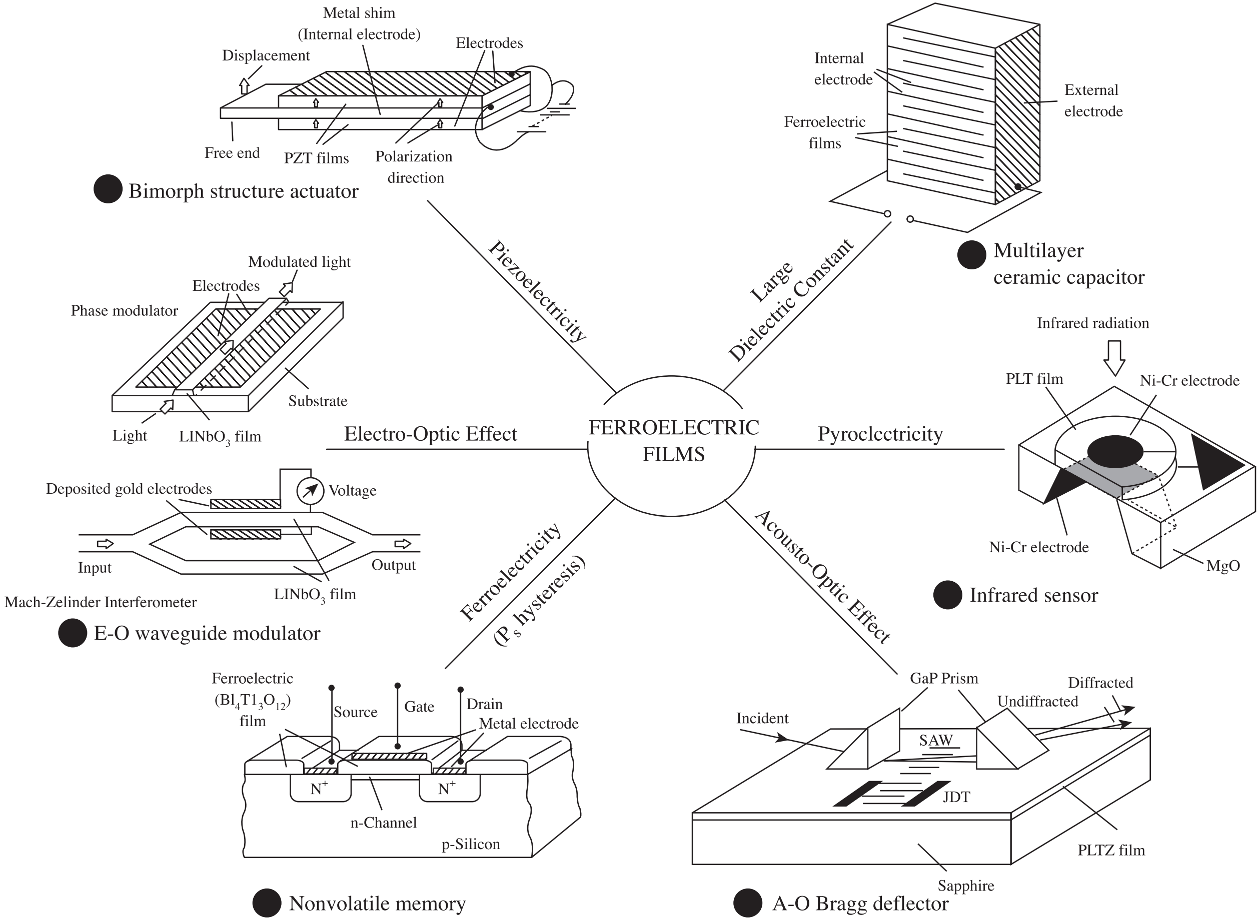
From Li, C.-Y. and Xu, Y., Ferroelectric materials, in *Handbook of Photonics*, Gupta, M.C., Ed., CRC Press, Boca Raton, FL, 1997, p. 93. Originally from Xu, Y., *Ferroelectric Materials and Their Applications*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 1991. With permission.

General Physical Properties of Ferroelectric Materials

Chemical Formula	Point Group*	Phase Transition Temperature (°C)	Spontaneous Polarization (μC/cm²)	Density (g/cm³)	Melting Point (°C)
$BaTiO_3$	$m3m \rightarrow \mathbf{4mm} \rightarrow mm2 \rightarrow 3m$	120, 5, –90	26	6.02	1618
$KNbO_3$	$m3m \rightarrow 4mm \rightarrow \mathbf{mm2} \rightarrow 3m$	435, 225, –10	30		1050
$KTaO_3$	$m3m \rightarrow 4mm \rightarrow \mathbf{mm2} \rightarrow 3m$				
$KTa_{1-x}Nb_xO_3$	$m3m \rightarrow 4mm \rightarrow \mathbf{mm2} \rightarrow 3m$				
$Pb_{1-x}La_x(Zr_yTi_{1-y})_{1-.0.25x}V^B_{0.25x}O_3$				7.80	
$LiNbO_3$	$\bar{3}m \rightarrow \mathbf{3m}$	1210	71	4.64	1240
$LiTaO_3$	$\bar{3}m \rightarrow \mathbf{3m}$	665	50	7.45	1650
$Ba_{0.4}Sr_{0.6}Nb_2O_6$	$(4/m)mm \rightarrow \mathbf{4mm} \rightarrow m$	75, –213	32	~5.4	~1480
$Ba_2NaNb_5O_{15}$	$(4/m)mm \rightarrow 4mm \rightarrow \mathbf{mm2}$	560, 300	40	5.40	~1450
$K_3Li_2Nb_5O_{15}$	$(4/m)mm \rightarrow \mathbf{4mm}$	430	~40		1250
$(K_xNa_{1-x})_{0.4}(Sr_yBa_{1-y})_{0.8}Nb_2O_6$	$(4/m)mm \rightarrow \mathbf{4mm}$		~30	5.16	
KH_2PO_4(KDP)	$\mathbf{\bar{4}2m} \rightarrow mm2$	–150	–4.8	2.34	Decomposes at 180°C
KH_2AsO_4	$\mathbf{\bar{4}2m} \rightarrow mm2$	–176			
RbH_2PO_4	$\mathbf{\bar{4}2m} \rightarrow mm2$	–126			
$(NH_2CH_2COOH)_3 \cdot H_2SO_4$ (TGS)	$2/m \rightarrow 2$	49	2.8	1.69	
$(NH_2CH_2COOH)_3 \cdot H_2SeO_4$	$2/m \rightarrow 2$	26			
$KTiOPO_4$	$mmm \rightarrow \mathbf{mm2}$	943	~17		
$Bi_4Ti_3O_{12}$	$(4/m)mm \rightarrow \mathbf{m}$	675	50, *a*-axis 4, *c*-axis	6.1	
β-$Gd_2(MoO)_3$	$\bar{4}2m \rightarrow \mathbf{mm2}$	159	0.17		1175
$5PbO \cdot 3GeO_2$, or $Pb_5Ge_3O_{11}$	$\bar{6} \rightarrow 3$	177	4.8	7.33	738
SbSI	$mmm \rightarrow \mathbf{mm2}$	22	25 (0°C)	5.25	

* Point groups in bold are point groups at room temperature.

From Li, C.-Y. and Xu, Y., Ferroelectric materials, in *Handbook of Photonics*, Gupta, M.C., Ed., CRC Press, Boca Raton, FL, 1997, p. 94. Originally from Xu, Y., *Ferroelectric Materials and Their Applications*, Elsevier Science Publishers B.V., Amsterdam, The Netherlands, 1991. With permission.



Applications of the ferroelectric thin films. (From Li, C.-Y. and Xu, Y., Ferroelectric materials, in *Handbook of Photonics*, Gupta, M.C., Ed., CRC Press, Boca Raton, FL, 1997, p. 100.)

The Principal Photometric Units

Quantity	Defining Equation	SI Unit	US Unit	Conversion[1] Factor
Luminous flux	$F = Km \int_0^\infty V(\lambda)\, P(\lambda)\, d\lambda$	lumens	lumens	1
Intensity	$I = dF/d\Omega$	candela (lumens/steradian)	candela	1
Luminance	$L = dI/dA_e$	candela/m^2 (A_e is emitting area)	ft-lamberts (1 cd/π ft^2)	0.2919
Illuminance	$E = dF/dA_i$	lux (lum/m^2) (A_i is illumin'd area)	Foot-candle (1 lum/ft^2)	0.09294

[1] From metric into U.S. units.

From Infante, C., Electronic displays, in *Handbook of Photonics*, Gupta, M.C., ed., CRC Press, Boca Raton, FL, 1997, p. 770.

Dielectric Constants of Common Materials

Material	Dielectric Constant (k)
Vacuum	1
Air	1.00054
Water	78
Paper	3.5
Porcelain	6.5
Fused quartz	3.8
Pyrex glass	4.5
Polyethylene	2.3
Amber	2.7
Polystyrene	2.6
Teflon	2.1
Transformer oil	4.5
Titanium dioxide	100

From Morgan, D., Applications, standards, and products for grounding and shielding, in *Instrument Engineers' Handbook: Process Software and Digital Networks,* 3rd ed., Liptak, B., Ed., CRC Press, Boca Raton, FL, 2002.

Characteristics of Coaxial Cables

Cable Type	Characteristic Impedance	Common Usage
RG-6	75	Broadband, Carrier Band Drop
RG-8	50	Thick Ethernet
RG-11	75	Broadband, Carrier Band Trunk
RG-58	50	Thin Ethernet
RG-59	75	Broadband Drop
RG-62	93	ARCnet

Note: Some references include the dash in RG-X, others do not.

From Barton, C.C., PLC proprietary and open networks, in *Instrument Engineers' Handbook: Process Software and Digital Networks,* 3rd ed., Liptak, B., Ed., CRC Press, Boca Raton, FL, 2002.

Dry Saturated Steam: Temperature Table

		Specific Volume, ft³/lbm†			Enthalpy, Btu/lbm†			Entropy, Btu/lbm R†		
Temp., °F/°C	Abs. Press., PSIA P†	Sat. Liquid υ_f	Evap. υ_{fg}	Sat. Vapor υ_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g
32/0	0.08854	0.01602	3306	3306	0.00	1075.8	1075.8	0.0000	2.1877	2.1877
35/1.7	0.09995	0.01602	2947	2947	3.02	1074.1	1077.1	0.0061	2.1709	2.1770
40/4.4	0.12170	0.01602	2444	2444	8.05	1071.3	1079.3	0.0162	2.1435	2.1597
45/7.2	0.14752	0.01602	2036.4	2036.4	13.06	1068.4	1081.5	0.0262	2.1167	2.1429
50/10	0.17811	0.01603	1703.2	1703.2	18.07	1065.6	1083.7	0.0361	2.0903	2.1264
60/15.6	0.2563	0.01604	1206.6	1206.7	28.06	1059.9	1088.0	0.0555	2.0393	2.0948
70/21.1	0.3631	0.01606	867.8	867.9	38.04	1054.3	1092.3	0.0745	1.9902	2.0647
80/26.7	0.5069	0.01608	633.1	633.1	48.02	1048.6	1096.6	0.0932	1.9428	2.0360
90/32.2	0.6982	0.01610	468.0	468.0	57.99	1042.9	1100.9	0.1115	1.8972	2.0087
100/37.8	0.9492	0.01613	350.3	350.4	67.97	1037.2	1105.2	0.1295	1.8531	1.9826
110/43	1.2748	0.01617	265.3	265.4	77.94	1031.6	1109.5	0.1471	1.8106	1.9577
120/49	1.6924	0.01620	203.25	203.27	87.92	1025.8	1113.7	0.1645	1.7694	1.9339
130/54	2.2225	0.01625	157.32	157.34	97.90	1020.0	1117.9	0.1816	1.7296	1.9112
140/60	2.8886	0.01629	122.99	123.01	107.89	1014.1	1122.0	0.1984	1.6910	1.8894
150/66	3.718	0.01634	97.06	97.07	117.89	1008.2	1126.1	0.2149	1.6537	1.8685
160/71	4.741	0.01639	77.27	77.29	127.89	1002.3	1130.2	0.2311	1.6174	1.8485
170/77	5.992	0.01645	62.04	62.06	137.90	996.3	1134.2	0.2472	1.5822	1.8293
180/82	7.510	0.01651	50.21	50.23	147.92	990.2	1138.1	0.2630	1.5480	1.8109
190/88	9.339	0.01657	40.94	40.96	157.95	984.1	1142.0	0.2785	1.5147	1.7932
200/93	11.526	0.01663	33.62	33.64	167.99	977.9	1145.9	0.2938	1.4824	1.7762
210/90	14.123	0.01670	27.80	27.82	178.05	971.6	1149.7	0.3090	1.4508	1.7598
212/100	14.696	0.01672	26.78	26.80	180.07	970.3	1150.4	0.3120	1.4446	1.7566
220/104	17.186	0.01677	23.13	23.15	188.13	965.2	1153.4	0.3239	1.4201	1.7440
230/110	20.780	0.01684	19.365	19.382	198.23	958.8	1157.0	0.3387	1.3901	1.7288
240/116	24.969	0.01692	16.306	16.323	208.34	952.2	1160.5	0.3531	1.3609	1.7140
250/121	29.825	0.01700	13.804	13.821	218.48	945.5	1164.0	0.3675	1.3323	1.6998
260/127	35.429	0.01709	11.746	11.763	228.64	938.7	1167.3	0.3817	1.3043	1.6860
270/132	41.858	0.01717	10.044	10.061	238.84	931.8	1170.6	0.3958	1.2769	1.6727
280/138	49.203	0.01726	8.628	8.645	249.06	924.7	1173.8	0.4096	1.2501	1.6597
290/143	57.556	0.01735	7.444	7.461	259.31	917.5	1176.8	0.4234	1.2238	1.6472
300/149	67.013	0.01745	6.449	6.466	269.59	910.1	1179.7	0.4369	1.1980	1.6350
310/154	77.68	0.01755	5.609	5.626	279.92	902.6	1182.5	0.4504	1.1727	1.6231
320/160	89.66	0.01765	4.896	4.914	290.28	894.9	1185.2	0.4637	1.1478	1.6115
330/166	103.06	0.01776	4.289	4.307	300.68	887.0	1187.7	0.4769	1.1233	1.6002
340/171	118.01	0.01787	3.770	3.788	311.13	879.0	1190.1	0.4900	1.0992	1.5891
350/177	134.63	0.01799	3.324	3.342	321.63	870.7	1192.3	0.5029	1.0754	1.5783
360/182	153.04	0.01811	2.939	2.957	332.18	862.2	1194.4	0.5158	1.0519	1.5677
370/188	173.37	0.01823	2.606	2.625	342.79	853.5	1196.3	0.5286	1.0287	1.5573
380/193	195.77	0.01836	2.317	2.335	353.45	844.6	1198.1	0.5413	1.0059	1.5471
390/199	220.37	0.01850	2.0651	2.0836	364.17	835.4	1199.6	0.5539	0.9832	1.5371
400/204	247.31	0.01864	1.8447	1.8633	374.97	826.0	1201.0	0.5664	0.9608	1.5272
410/210	276.75	0.01878	1.6512	1.6700	385.83	816.3	1202.1	0.5788	0.9386	1.5174
420/216	308.83	0.01894	1.4811	1.5000	396.77	806.3	1203.1	0.5912	0.9166	1.5078
430/221	343.72	0.01910	1.3308	1.3499	407.79	796.0	1203.8	0.6035	0.8947	1.4982
440/227	381.59	0.01926	1.1979	1.2171	418.90	785.4	1204.3	0.6158	0.8730	1.4887
450/232	422.6	0.0194	1.0799	1.0993	430.1	774.5	1204.6	0.6280	0.8513	1.4793
460/238	466.9	0.0196	0.9748	0.9944	441.4	763.2	1204.6	0.6402	0.8298	1.4700
470/243	514.7	0.0198	0.8811	0.9009	452.8	751.5	1204.3	0.6523	0.8083	1.4606

Dry Saturated Steam: Temperature Table (continued)

		Specific Volume, ft^3/lbm†			Enthalpy, Btu/lbm†			Entropy, Btu/lbm R†		
Temp., °F/°C t	Abs. Press., PSIA P†	Sat. Liquid υ_f	Evap. υ_{fg}	Sat. Vapor υ_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Evap. s_{fg}	Sat. Vapor s_g
480/249	566.1	0.0200	0.7972	0.8172	464.4	739.4	1203.7	0.6645	0.7868	1.4513
490/254	621.4	0.0202	0.7221	0.7423	476.0	726.8	1202.8	0.6766	0.7653	1.4419
500/260	680.8	0.0204	0.6545	0.6749	487.8	713.9	1201.7	0.6887	0.7438	1.4325
520/271	812.4	0.0209	0.5385	0.5594	511.9	686.4	1198.2	0.7130	0.7006	1.4136
540/282	962.5	0.0215	0.4434	0.4649	536.6	656.6	1193.2	0.7374	0.6568	1.3942
560/293	1133.1	0.0221	0.3647	0.3868	562.2	624.2	1186.4	0.7621	0.6121	1.3742
580/304	1325.8	0.0228	0.2989	0.3217	588.9	588.4	1177.3	0.7872	0.5659	1.3532
600/316	1542.9	0.0236	0.2432	0.2668	617.0	548.5	1165.5	0.8131	0.5176	1.3307
620/327	1786.6	0.0247	0.1955	0.2201	646.7	503.6	1150.3	0.8398	0.4664	1.3062
640/338	2059.7	0.0260	0.1538	0.1798	678.6	452.0	1130.5	0.8679	0.4110	1.2789
660/349	2365.4	0.0278	0.1165	0.1442	714.2	390.2	1104.4	0.8987	0.3485	1.2472
680/360	2708.1	0.0305	0.0810	0.1115	757.3	309.9	1067.2	0.9351	0.2719	1.2071
700/371	3093.7	0.0369	0.0392	0.0761	823.3	172.1	995.4	0.9905	0.1484	1.1389
705.4/374.1	3206.2	0.0503	0	0.0503	902.7	0	902.7	1.0580	0	1.0580

† PSIA = 0.069 bar (abs); ft^3/lbm = 62.4 l/kg; Btu/lbm = 0.556 Kcal/kg

From Liptak, B.G., Ed., *Instrument Engineers' Handbook: Process Software and Digital Networks,* 3rd ed., CRC Press, Boca Raton, FL, 2002, pp. 817–818. Originally abridged from *Thermodynamic Properties of Steam,* by Joseph H. Keenan and Fredrick G. Keyes. © 1936, by Joseph H. Keenan and Frederick G. Keyes. Published by John Wiley & Sons, Inc., New York.

Properties of Superheated Steam

Abs. Press., PSIA (Sat. Temp. °F)	Temperature, °F/°C												
	200/93	220/104	300/149	350/177	400/204	450/232	500/260	550/288	600/316	700/371	800/427	900/482	1000/538
υ	392.6	404.5	452.3	482.2	512.0	541.8	571.6	601.4	631.2	690.8	750.4	809.9	869.5
1 *h*	1150.4	1159.5	1195.8	1218.7	1241.7	1264.9	1288.3	1312.0	1335.7	1383.8	1432.8	1482.7	1533.5
(101.74) *s*	2.0512	2.0647	2.1153	2.1444	2.1720	2.1983	2.2233	2.2468	2.2702	2.3137	2.3542	2.3923	2.4283
υ	78.16	80.59	90.25	96.26	102.26	108.24	114.22	120.19	126.16	138.10	150.03	161.95	173.87
5 *h*	1148.8	1158.1	1195.0	1218.1	1241.2	1264.5	1288.0	1311.7	1335.4	1383.6	1432.7	1482.6	1533.4
(162.24) *s*	1.8718	1.8857	1.9370	1.9664	1.9942	2.0205	2.0456	2.0692	2.0927	2.1361	2.1767	2.2148	2.2509
υ	38.85	40.09	45.00	48.03	51.04	54.05	57.05	60.04	63.03	69.01	74.98	80.95	86.92
10 *h*	1146.6	1156.2	1193.9	1217.2	1240.6	1264.0	1287.5	1311.3	1335.1	1383.4	1432.5	1482.4	1533.1
(193.21) *s*	1.7927	1.8071	1.8595	1.8892	1.9172	1.9436	1.9689	1.9924	2.0160	2.0596	2.1002	2.1383	2.1744
υ		27.15	30.53	32.62	34.68	36.73	38.78	40.82	42.86	46.94	51.00	55.07	59.13
14.696 *h*		1154.4	1192.8	1216.4	1239.9	1263.5	1287.1	1310.9	1335.8	1383.2	1432.3	1482.3	1533.1
(212.00) *s*		1.7624	1.8160	1.8460	1.8743	1.9008	1.9261	1.9498	1.9734	2.0170	2.0576	2.0958	2.1319
υ			22.36	23.91	25.43	26.95	28.46	29.97	31.47	34.47	37.46	40.45	43.44
20 *h*			1191.6	1215.6	1239.2	1262.9	1286.6	1310.5	1334.4	1382.9	1432.1	1482.1	1533.0
(227.96) *s*			1.7808	1.8112	1.8396	1.8664	1.8918	1.9160	1.9392	1.9829	2.0235	2.0618	2.0978
υ			11.040	11.843	12.628	13.401	14.168	14.93	15.688	17.198	18.702	20.20	21.70
40 *h*			1186.8	1211.9	1236.5	1260.7	1284.8	1308.9	1333.1	1381.9	1431.3	1481.4	1532.4
(267.25) *s*			1.6994	1.7314	1.7608	1.7881	1.8140	1.8384	1.8619	1.9058	1.9467	1.9850	2.0214
υ			7.259	7.818	8.357	8.884	9.403	9.916	10.427	11.441	12.449	13.452	14.454
60 *h*			1181.6	1208.2	1233.6	1258.5	1283.0	1307.4	1331.8	1380.9	1430.5	1480.8	1531.9
(292.71) *s*			1.6492	1.6830	1.7135	1.7416	1.7678	1.7926	1.8162	1.8605	1.9015	1.9400	1.9762
υ				5.803	6.220	6.624	7.020	7.410	7.797	8.562	9.322	10.077	10.830
80 *h*				1204.3	1230.7	1256.1	1281.1	1305.8	1330.5	1379.9	1429.7	1480.1	1531.3
(312.03) *s*				1.6475	1.6791	1.7078	1.7346	1.7598	1.7836	1.8281	1.8694	1.9079	1.9442
υ				4.592	4.937	5.268	5.589	5.905	6.218	6.835	7.446	8.052	8.656
100 *h*				1200.1	1227.6	1253.7	1279.1	1304.2	1329.1	1378.9	1428.9	1479.5	1530.8
(327.81) *s*				1.6188	1.6518	1.6813	1.7085	1.7339	1.7581	1.8029	1.8443	1.8829	1.9193
υ				3.783	4.081	4.363	4.636	4.902	5.165	5.683	6.195	6.702	7.207
120 *h*				1195.7	1224.4	1251.3	1277.2	1302.5	1327.7	1377.8	1428.1	1478.8	1530.2
(341.25) *s*				1.5944	1.6287	1.6591	1.6869	1.7127	1.7370	1.7822	1.8237	1.8625	1.8990
υ					3.468	3.715	3.954	4.186	4.413	4.861	5.301	5.738	6.172
140 *h*					1221.1	1248.7	1275.2	1300.9	1326.4	1376.8	1427.3	1478.2	1529.7
(353.02) *s*					1.6087	1.6399	1.6683	1.6945	1.7190	1.7645	1.8063	1.8451	1.8817

Properties of Superheated Steam (continued)

Abs. Press., PSIA (Sat. Temp. °F)	Temperature, °F/°C												
	200/93	220/104	300/149	350/177	400/204	450/232	500/260	550/288	600/316	700/371	800/427	900/482	1000/538
υ					3.008	3.230	3.443	3.648	3.849	4.244	4.631	5.015	5.396
160 *h*					1217.6	1246.1	1273.1	1299.3	1325.0	1375.7	1426.4	1477.5	1529.1
(363.53) *s*					1.5908	1.6230	1.6519	1.6785	1.7033	1.7491	1.7911	1.8301	1.8667
υ					2.649	2.852	3.044	3.229	3.411	3.764	4.110	4.452	4.792
180 *h*					1214.0	1243.5	1271.0	1297.6	1323.5	1374.7	1425.6	1476.8	1528.6
(373.06) *s*					1.5745	1.6077	1.6373	1.6642	1.6894	1.7355	1.7776	1.8167	1.8534
υ					2.361	2.549	2.726	2.895	3.060	3.380	3.693	4.002	4.309
200 *h*					1210.3	1240.7	1268.9	1295.8	1322.1	1373.6	1424.8	1476.2	1528.0
(381.79) *s*					1.5594	1.5937	1.6240	1.6513	1.6767	1.7232	1.7655	1.8048	1.8415
υ					2.125	2.301	2.465	2.621	2.772	3.066	3.352	3.634	3.913
220 *h*					1206.5	1237.9	1266.7	1294.1	1320.7	1372.6	1424.0	1475.5	1527.5
(389.86) *s*					1.5453	1.5808	1.6117	1.6395	1.6652	1.7120	1.7545	1.7939	1.8308
υ					1.9276	2.094	2.247	2.393	2.533	2.804	3.068	3.327	3.584
240 *h*					1202.5	1234.9	1264.5	1292.4	1319.2	1371.5	1423.2	1474.8	1526.9
(397.37) *s*					1.5319	1.5686	1.6003	1.6286	1.6546	1.7017	1.7444	1.7839	1.8209
υ						1.9183	2.063	2.199	2.330	2.582	2.827	3.067	3.305
260 *h*						1232.0	1262.3	1290.5	1317.7	1370.4	1422.3	1474.2	1526.3
(404.42) *s*						1.5573	1.5897	1.6184	1.6447	1.6922	1.7352	1.7748	1.8118
υ						1.7674	1.9047	2.033	2.156	2.392	2.621	2.845	3.066
280 *h*						1228.9	1260.0	1288.7	1316.2	1369.4	1421.5	1473.5	1525.8
(411.05) *s*						1.5464	1.5796	1.6087	1.6354	1.6834	1.7265	1.7662	1.8033
υ						1.6364	1.7675	1.8891	2.005	2.227	2.442	2.652	2.859
300 *h*						1225.8	1257.6	1286.8	1314.7	1368.3	1420.6	1427.8	1525.2
(417.33) *s*						1.5360	1.5701	1.5998	1.6268	1.6751	1.7184	1.7582	1.7954
υ						1.3734	1.4923	1.6010	1.7036	1.8980	2.084	2.266	2.445
350 *h*						1217.7	1251.5	1282.1	1310.9	1365.5	1418.5	1471.1	1523.8
(431.72) *s*						1.5119	1.5481	1.5792	1.6070	1.6563	1.7002	1.7403	1.7777
υ						1.1744	1.2851	1.3843	1.4770	1.6508	1.8161	1.9767	2.134
400 *h*						1208.8	1245.1	1277.2	1306.9	1362.7	1416.4	1469.4	1522.4
(444.59) *s*						1.4892	1.5281	1.5607	1.5894	1.6398	1.6842	1.7247	1.7623

Abs. Press., PSIA (Sat. Temp. °F)	Temperature, °F/°C													
	500/260	550/288	600/316	620/327	640/338	660/349	680/360	700/371	800/427	900/482	1000/538	1200/649	1400/760	1600/871
υ	1.1231	1.2155	1.3005	1.3332	1.3652	1.3967	1.4278	1.4584	1.6074	1.7516	1.8928	2.170	2.443	2.714
450 *h*	1238.4	1272.0	1302.8	1314.6	1326.2	1337.5	1348.8	1359.9	1414.3	1467.7	1521.0	1628.6	1738.7	1851.9
(456.28) *s*	1.5095	1.5437	1.5735	1.5845	1.5951	1.6054	1.6153	1.6250	1.6699	1.7108	1.7486	1.8177	1.8803	1.9381
υ	0.9927	1.0800	1.1591	1.1893	1.2188	1.2478	1.2763	1.3044	1.4405	1.5715	1.6996	1.9504	2.197	2.442
500 *h*	1231.3	1266.8	1298.6	1310.7	1322.6	1334.2	1345.7	1357.0	1412.1	1466.0	1519.6	1627.6	1737.9	1851.3
(467.01) *s*	1.4919	1.5280	1.5588	1.5701	1.5810	1.5915	1.6016	1.6115	1.6571	1.6982	1.7363	1.8056	1.8683	1.9262
υ	0.8852	0.9686	1.0431	1.0714	1.0989	1.1259	1.1523	1.1783	1.3038	1.4241	1.5414	1.7706	1.9957	2.219
550 *h*	1223.7	1261.2	1294.3	1306.8	1318.9	1330.8	1342.5	1354.0	1409.9	1464.3	1518.2	1626.6	1737.1	1850.6
(476.94) *s*	1.4751	1.5131	1.5451	1.5568	1.5680	1.5787	1.5890	1.5991	1.6452	1.6868	1.7250	1.7946	1.8575	1.9155
υ	0.7947	0.8753	0.9463	0.9729	0.9988	1.0241	1.0489	1.0732	1.1899	1.3013	1.4096	1.6208	1.8279	2.033
600 *h*	1215.7	1255.5	1289.9	1302.7	1315.2	1327.4	1339.3	1351.1	1407.7	1462.5	1516.7	1625.5	1736.3	1850.0
(486.21) *s*	1.4586	1.4990	1.5323	1.5443	1.5558	1.5667	1.5773	1.5875	1.6343	1.6762	1.7147	1.7846	1.8476	1.9056
υ		0.7277	0.7934	0.8177	0.8411	0.8639	0.8860	0.9077	1.0108	1.1082	1.2024	1.3853	1.5641	1.7405
700 *h*		1243.2	1280.6	1294.3	1307.5	1320.3	1332.8	1345.0	1403.2	1459.0	1513.9	1623.5	1734.8	1848.8
(503.10) *s*		1.4722	1.5084	1.5212	1.5333	1.5449	1.5559	1.5665	1.6147	1.6573	1.6963	1.7666	1.8299	1.8881
υ		0.6154	0.6779	0.7006	0.7223	0.7433	0.7635	0.7833	0.8763	0.9633	1.0470	1.2088	1.3662	1.5214
800 *h*		1229.8	1270.7	1285.4	1299.4	1312.9	1325.9	1338.6	1398.6	1455.4	1511.0	1621.4	1733.2	1847.5
(518.23) *s*		1.4467	1.4863	1.5000	1.5129	1.5250	1.5366	1.5476	1.5972	1.6407	1.6801	1.7510	1.8146	1.8729
υ		0.5264	0.5873	0.6089	0.6294	0.6491	0.6680	0.6863	0.7716	0.8506	0.9262	1.0714	1.2124	1.3509
900 *h*		1215.0	1260.1	1275.9	1290.9	1305.1	1318.8	1332.1	1393.9	1451.8	1508.1	1619.3	1731.6	1846.3
(531.98) *s*		1.4216	1.4653	1.4800	1.4938	1.5066	1.5187	1.5303	1.5814	1.6257	1.6656	1.7371	1.8009	1.8595
υ		0.4533	0.5140	0.5350	0.5546	0.5733	0.5912	0.6084	0.6878	0.7604	0.8294	0.9615	1.0893	1.2146
1000 *h*		1198.3	1248.8	1265.9	1281.9	1297.0	1311.4	1325.3	1389.2	1448.2	1505.1	1617.3	1730.0	1845.0
(544.61) *s*		1.3961	1.4450	1.4610	1.4757	1.4893	1.5021	1.5141	1.5670	1.6121	1.6525	1.7245	1.7886	1.8474
υ			0.4532	0.4738	0.4929	0.5110	0.5281	0.5445	0.6191	0.6866	0.7503	0.8716	0.9885	1.1031
1100 *h*			1236.7	1255.3	1272.4	1288.5	1303.7	1318.3	1384.3	1444.5	1502.2	1615.2	1728.4	1843.8
(556.31) *s*			1.4251	1.4425	1.4583	1.4728	1.4862	1.4989	1.5535	1.5995	1.6405	1.7130	1.7775	1.8363
υ			0.4016	0.4222	0.4410	0.4586	0.4752	0.4909	0.5617	0.6250	0.6843	0.7967	0.9046	1.0101
1200 *h*			1223.5	1243.9	1262.4	1279.6	1295.7	1311.0	1379.3	1440.7	1499.2	1613.1	1726.9	1842.5
(567.22) *s*			1.4052	1.4243	1.4413	1.4568	1.4710	1.4843	1.5409	1.5879	1.6293	1.7025	1.7672	1.8263
υ			0.3174	0.3390	0.3580	0.3753	0.3912	0.4062	0.4714	0.5281	0.5805	0.6789	0.7727	0.8640
1400 *h*			1193.0	1218.4	1240.4	1260.3	1278.5	1295.5	1369.1	1433.1	1493.2	1608.9	1723.7	1840.0
(587.10) *s*			1.3639	1.3877	1.4079	1.4258	1.4419	1.4567	1.5177	1.5666	1.6093	1.6836	1.7489	1.8083

Abs. Press., PSIA (Sat. Temp. °F)	Temperature, °F/°C													
	500/260	550/288	600/316	620/327	640/338	660/349	680/360	700/371	800/427	900/482	1000/538	1200/649	1400/760	1600/871
υ				0.2733	0.2936	0.3112	0.3271	0.3417	0.4034	0.4553	0.5027	0.5906	0.6738	0.7545
1600 *h*				1187.8	1215.2	1238.7	1259.6	1278.7	1358.4	1425.3	1487.0	1604.6	1720.5	1837.5
(604.90) *s*				1.3489	1.3741	1.3952	1.4137	1.4303	1.4964	1.5476	1.5914	1.6669	1.7328	1.7926
υ					0.2407	0.2597	0.2760	0.2907	0.3502	0.3986	0.4421	0.5218	0.5968	0.6693
1800 *h*					1185.1	1214.0	1238.5	1260.3	1347.2	1417.4	1480.8	1600.4	1717.3	1835.0
(621.03) *s*					1.3377	1.3638	1.3855	1.4044	1.4765	1.5301	1.5752	1.6520	1.7185	1.7786
υ					0.1936	0.2161	0.2337	0.2489	0.3074	0.3532	0.3935	0.4668	0.5352	0.6011
2000 *h*					1145.6	1184.9	1214.8	1240.0	1335.5	1409.2	1474.5	1596.1	1714.1	1832.5
(635.82) *s*					1.2945	1.3300	1.3564	1.3783	1.4576	1.5139	1.5603	1.6384	1.7055	1.7660
υ							0.1484	0.1686	0.2294	0.2710	0.3061	0.3678	0.4244	0.4784
2500 *h*							1132.3	1176.8	1303.6	1387.8	1458.4	1585.3	1706.1	1826.2
(668.13) *s*							1.2687	1.3073	1.4127	1.4772	1.5273	1.6088	1.6775	1.7389
υ								0.0984	0.1760	0.2159	0.2476	0.3018	0.3505	0.3966
3000 *h*								1060.7	1267.2	1365.0	1441.8	1574.3	1698.0	1819.9
(695.36) *s*								1.1966	1.3690	1.4439	1.4984	1.5837	1.6540	1.7163
υ									0.1583	0.1981	0.2288	0.2806	0.3267	0.3703
3206.2 *h*									1250.5	1355.2	1434.7	1569.8	1694.6	1817.2
(705.40) *s*									1.3508	1.4309	1.4874	1.5742	1.6452	1.7080
υ								0.0306	0.1364	0.1762	0.2058	0.2546	0.2977	0.3381
3500 *h*								780.5	1224.9	1340.7	1424.5	1563.3	1689.8	1813.6
S								0.9515	1.3241	1.4127	1.4723	1.5615	1.6336	1.6968
υ								0.0287	0.1052	0.1462	0.1743	0.2192	0.2581	0.2943
4000 *h*								763.8	1174.8	1314.4	1406.8	1552.1	1681.7	1807.2
S								0.9347	1.2757	1.3827	1.4482	1.5417	1.6154	1.6795
υ								0.0276	0.0798	0.1226	0.1500	0.1917	0.2273	0.2602
4500 *h*								753.5	1113.9	1286.5	1388.4	1540.8	1673.5	1800.9
S								0.9235	1.2204	1.3529	1.4253	1.5235	1.5990	1.6640
υ								0.0268	0.0593	0.1036	0.1303	0.1696	0.2027	0.2329
5000 *h*								746.4	1047.1	1256.5	1369.5	1529.5	1665.3	1794.5
S								0.9152	1.1622	1.3231	1.4034	1.5066	1.5839	1.6499
υ								0.0262	0.0463	0.0880	0.1143	0.1516	0.1825	0.2106
5500 *h*								741.3	985.0	1224.1	1349.3	1518.2	1657.0	1788.1
S								0.9090	1.1093	1.2930	1.3821	1.4908	1.5699	1.6369

From Liptak, B.G., Ed., *Instrument Engineers' Handbook: Process Software and Digital Networks,* 3rd ed., CRC Press, Boca Raton, FL, 2002, pp. 819–822. Originally abridged from *Thermodynamic Properties of Steam,* by Joseph H. Keenan and Fredrick G. Keyes. © 1936, by Joseph H. Keenan and Frederick G. Keyes. Published by John Wiley & Sons, Inc., New York.

Properties of Water at Various Temperatures from 40 to 540°F (4.4 to 282.2°C)

Temp. °F	Temp. °C	Specific Volume* ft^3/lb	Specific Gravity	Weight* (lb/ft^3)	Vapor Pressure* PSIA
40	4.4	.01602	1.0013	62.42	0.1217
50	10.0	.01603	1.0006	62.38	0.1781
60	15.6	.01604	1.0000	62.34	0.2563
70	21.1	.01606	0.9987	62.27	0.3631
80	26.7	.01608	0.9975	62.19	0.5069
90	32.2	.01610	0.9963	62.11	0.6982
100	37.8	.01613	0.9944	62.00	0.9492
120	48.9	.01620	0.9901	61.73	1.692
140	60.0	.01629	0.9846	61.39	2.889
160	71.1	.01639	0.9786	61.01	4.741
180	82.2	.01651	0.9715	60.57	7.510
200	93.3	.01663	0.9645	60.13	11.526
212	100.0	.01672	0.9593	59.81	14.696
220	104.4	.01677	0.9565	59.63	17.186
240	115.6	.01692	0.9480	59.10	24.97
260	126.7	.01709	0.9386	58.51	35.43
280	137.8	.01726	0.9293	58.00	49.20
300	148.9	.01745	0.9192	57.31	67.01
320	160.0	.01765	0.9088	56.66	89.66
340	171.1	.01787	0.8976	55.96	118.01
360	182.2	.01811	0.8857	55.22	153.04
380	193.3	.01836	0.8736	54.47	195.77
400	204.4	.01864	0.8605	53.65	247.31
420	215.6	.01894	0.8469	52.80	308.83
440	226.7	.01926	0.8328	51.92	381.59
460	237.8	.0196	0.8183	51.02	466.9
480	248.9	.0200	0.8020	50.00	566.1
500	260.0	.0204	0.7863	49.02	680.8
520	271.1	.0209	0.7674	47.85	812.4
540	282.2	.0215	0.7460	46.51	962.5

*ft^3/lb = 62.4 l/Kg; lb/ft^3 = 0.016 Kg/l; PSIA = 0.069 bar (abs). Computed from Keenan & Keyes Steam Table.

From Liptak, B.G., Ed., *Instrument Engineers' Handbook: Process Software and Digital Networks,* CRC Press, Boca Raton, FL, 2002, p. 823.

Atomic Mass of Selected Elements

Atomic Number	Element	Symbol	Atomic Mass	Atomic Number	Element	Symbol	Atomic Mass
1	Hydrogen	H	1.008	48	Cadmium	Cd	112.4
2	Helium	He	4.003	49	Indium	In	114.82
3	Lithium	Li	6.941	50	Tin	Sn	118.69
4	Beryllium	Be	9.012	51	Antimony	Sb	121.75
5	Boron	B	10.81	52	Tellurium	Te	127.6
6	Carbon	C	12.01	53	Iodine	I	126.9
7	Nitrogen	N	14.01	54	Xenon	Xe	131.3
8	Oxygen	O	16.00	55	Cesium (–10°)	Ce	132.91
9	Fluorine	F	19.00	56	Barium	Ba	137.33
10	Neon	N	20.18	57	Lantium	La	138.91
11	Sodium	Na	22.99	58	Cerium	Ce	140.12
12	Magnesium	Mg	24.31	59	Praseodymium	Pr	140.91
13	Aluminum	Al	26.98	60	Neodymium	Nd	144.24
14	Silicon	Si	28.09	61	Promethium	Pm	(145)
15	Phosphorus (White)	P	30.97	62	Samarium	Sm	150.4
				63	Europium	Eu	151.96
16	Sulfur	S	32.06	64	Gadolinium	Gd	157.25
17	Chlorine	Cl	35.45	65	Terbium	Tb	158.93
18	Argon	Ar	39.95	66	Dysprosium	Dy	162.5
19	Potassium	K	39.1	67	Holmium	Ho	164.93
20	Calcium	Ca	40.08	68	Erbium	Er	167.26
21	Scandium	Sc	44.96	69	Thulium	Tm	168.93
22	Titanium	Ti	47.9	70	Ytterbium	Yb	173.04
23	Vanadium	V	50.94	71	Lutetium	Lu	174.97
24	Chromium	Cr	52.00	72	Hafnium	Hf	178.49
25	Manganese	Mn	54.94	73	Tantalum	Ta	180.95
26	Iron	Fe	55.85	74	Tungsten	W	183.85
27	Cobalt	Co	58.93	75	Rhenium	Re	186.2
28	Nichel	Ni	58.71	76	Osmium	Os	190.2
29	Copper	Cu	63.55	77	Iridium	Ir	192.22
30	Zinc	Zn	65.38	78	Platinum	Pt	195.09
31	Gallium	Ga	69.72	79	Gold	Au	196.97
32	Germanium	Ge	72.59	80	Mercury	Hg	200.59
33	Arsenic	As	74.92	81	Thallium	Tl	204.37
34	Selenium	Se	78.96	82	Lead	Pb	207.2
35	Bromine	Br	79.9	83	Bismuth	Bi	208.98
36	Krypton	Kr	83.8	84	Polonium	Po	(~210)
37	Rubidium	Rb	85.47	85	Asatine	At	(210)
38	Strontium	Sr	87.62	86	Radon	Rn	(222)
39	Yttrium	Y	88.91	87	Francium	Fr	(223)
40	Zirconium	Zr	91.22	88	Radium	Ra	226.03
41	Niobium	Nb	92.91	89	Actinium	Ac	(227)
42	Molybdenum	Mo	95.94	90	Thorium	Th	232.04
43	Technetium	Tc	98.91	91	Protoactinium	Pa	231.04
44	Ruthenium	Ru	101.07	92	Uranium	U	238.03
45	Rhodium	Rh	102.91	93	Neptunium	Np	237.05
46	Palladium	Pd	106.4	94	Plutonium	Pu	(244)
47	Silver	Ag	107.87	95	Americium	Am	(243)

Atomic Mass of Selected Elements (continued)

Atomic Number	Element	Symbol	Atomic Mass	Atomic Number	Element	Symbol	Atomic Mass
96	Curium	Cm	(247)	100	Fermium	Fm	(257)
97	Berkelium	Bk	(247)	101	Mendelevium	Md	(258)
98	Californium	Cf	(251)	102	Nobelium	No	(259)
99	Einsteinium	Es	(254)	103	Lawrencium	Lw	(260)

From Shackelford, J.F. and Alexander, W., *CRC Handbook of Materials Science & Engineering*, CRC Press, Boca Raton, FL, 2001, pp. 51–54. Data from James F. Shackelford, *Introduction to Materials Science for Engineers*, Second Edition, Macmillian Publishing Company, New York, pp. 686–688, (1988).

Solid Density of Selected Elements

Atomic Number	Element	Symbol	Solid Density (Mg/m3)	Atomic Number	Element	Symbol	Solid Density (Mg/m3)
3	Lithium	Li	0.533	51	Antimony	Sb	6.69
4	Beryllium	Be	1.85	52	Tellurium	Te	6.25
5	Boron	B	2.47	53	Iodine	I	4.95
6	Carbon	C	2.27	55	Cesium (–10°)	Ce	1.91
11	Sodium	Na	0.966	56	Barium	Ba	3.59
12	Magnesium	Mg	1.74	57	Lantium	La	6.17
13	Aluminum	Al	2.7	58	Cerium	Ce	6.77
14	Silicon	Si	2.33	59	Praseodymium	Pr	6.78
15	Phosphorus (White)	P	1.82	60	Neodymium	Nd	7.00
16	Sulfur	S	2.09	62	Samarium	Sm	7.54
19	Potassium	K	0.862	63	Europium	Eu	5.25
20	Calcium	Ca	1.53	64	Gadolinium	Gd	7.87
21	Scandium	Sc	2.99	65	Terbium	Tb	8.27
22	Titanium	Ti	4.51	66	Dysprosium	Dy	8.53
23	Vanadium	V	6.09	67	Holmium	Ho	8.80
24	Chromium	Cr	7.19	68	Erbium	Er	9.04
25	Manganese	Mn	7.47	69	Thulium	Tm	9.33
26	Iron	Fe	7.87	70	Ytterbium	Yb	6.97
27	Cobalt	Co	8.8	71	Lutertium	Lu	9.84
28	Nickel	Ni	8.91	72	Hafnium	Hf	13.28
29	Copper	Cu	8.93	73	Tantalum	Ta	16.67
30	Zinc	Zn	7.13	74	Tungsten	W	19.25
31	Gallium	Ga	5.91	75	Rhenium	Re	21.02
32	Germanium	Ge	5.32	76	Osmium	Os	22.58
33	Arsenic	As	5.78	77	Iridium	Ir	22.55
34	Selenium	Se	4.81	78	Platinum	Pt	21.44
37	Rubidium	Rb	1.53	79	Gold	Au	19.28
38	Strontium	Sr	2.58	81	Thallium	Tl	11.87
39	Yttrium	Y	4.48	82	Lead	Pb	11.34
40	Zirconium	Zr	6.51	83	Bismuth	Bi	9.80
41	Niobium	Nb	8.58	84	Polonium	Po	9.2
42	Molybdenum	Mo	10.22	90	Thorium	Th	11.72
43	Technetium	Tc	11.5	92	Uranium	U	19.05
44	Ruthenium	Ru	12.36	94	Plutonium	Pu	19.81
45	Rhodium	Rh	12.42				
46	Palladium	Pd	12.00				
47	Silver	Ag	10.50				
48	Cadmium	Cd	8.65				
49	Indium	In	7.29				
50	Tin	Sn	7.29				

From Shackelford, J.F. and Alexander, W., *CRC Handbook of Materials Science & Engineering*, CRC Press, Boca Raton, FL, 2001, pp. 55–57. Data from James F. Shackelford, *Introduction to Materials Science for Engineers*, Second Edition, Macmillian Publishing Company, New York, pp. 686–688, (1988).

Thermal Conductivity of Metals (Part 1)

T (K)	Aluminum	Cadmium	Chromium	Copper	Gold
1	7.8	48.7	0.401	28.7	4.4
2	15.5	89.3	0.802	57.3	8.9
3	23.2	104	1.20	85.5	13.1
4	30.8	92.0	1.60	113	17.1
5	38.1	69.0	1.99	138	20.7
6	45.1	44.2	2.38	159	23.7
7	51.5	28.0	2.77	177	26.0
8	57.3	18.0	3.14	189	27.5
9	62.2	12.2	3.50	195	28.2
10	66.1	8.87	3.85	196	28.2
11	69.0	6.91	4.18	193	27.7
12	70.8	5.56	4.49	185	26.7
13	71.5	4.67	4.78	176	25.5
14	71.3	4.01	5.04	166	24.1
15	70.2	3.55	5.27	156	22.6
16	68.4	3.16	5.48	145	20.9
18	63.5	2.62	5.81	124	17.7
20	56.5	2.26	6.01	105	15.0
25	40.0	1.79	6.07	68	10.2
30	28.5	1.56	5.58	43	7.6
35	21.0	1.41	5.03	29	6.1
40	16.0	1.32	4.30	20.5	5.2
45	12.5	1.25	3.67	15.3	4.6
50	10.0	1.20	3.17	12.2	4.2
60	6.7	1.13	2.48	8.5	3.8
70	5.0	1.08	2.08	6.7	3.58
80	4.0	1.06	1.82	5.7	3.52
90	3.4	1.04	1.68	5.14	3.48
100	3.0	1.03	1.58	4.83	3.45
200	2.37	0.993	1.11	4.13	3.27
273	2.36	0.975	0.948	4.01	3.18
300	2.37	0.968	0.903	3.98	3.15
400	2.4	0.947	0.873	3.92	3.12
500	2.37	0.92	0.848	3.88	3.09
600	2.32	(0.42)	0.805	3.83	3.04
700	2.26	(0.49)	0.757	3.77	2.98
800	2.2	(0.559)	0.713	3.71	2.92
900	2.13		0.678	3.64	2.85
1000	(0.93)		0.653	3.57	2.78
1100	(0.96)		0.636	3.5	2.71
1200	(0.99)		0.624	3.42	2.62
1400			0.611		

Values are in watt · cm^{-1} · K^{-1}.

Note: Values in parentheses are for liquid state.

These data apply only to metals of purity of at least 99.9%.

The third significant figure may not be accurate.

From Shackelford, J.F. and Alexander, W., *CRC Handbook of Materials Science and Engineering*, CRC Press, Boca Raton, FL, 2001, pp. 384–385. Data from Ho, C.Y., Powell, R.W., and Liley, P.E., Thermal Conductivity of Selected Materials, NSRDS–NBS–8 and NSRD–NBS–16, Part 2, National Standard Reference Data System–National Bureau of Standards, Part 1, 1966; Part 2, 1968.

Thermal Conductivity of Metals (Part 2)

T (K)	Iron	Lead	Magnesium	Mercury	Molybdenum
1	0.75	27.7	1.30		0.146
2	1.49	42.4	2.59		0.292
3	2.24	34.0	3.88		0.438
4	2.97	22.4	5.15		0.584
5	3.71	13.8	6.39		0.730
6	4.42	8.2	7.60		0.876
7	5.13	4.9	8.75		1.02
8	5.80	3.2	9.83		1.17
9	6.45	2.3	10.8		1.31
10	7.05	1.78	11.7		1.45
11	7.62	1.46	12.5		1.60
12	8.13	1.23	13.1		1.74
13	8.58	1.07	13.6		1.88
14	8.97	0.94	14.0		2.01
15	9.30	0.84	14.3		2.15
16	9.56	0.77	14.4		2.28
18	9.88	0.66	14.3		2.53
20	9.97	0.59	13.9		2.77
25	9.36	0.507	12.0		3.25
30	8.14	0.477	9.5		3.55
35	6.81	0.462	7.4		3.62
40	5.55	0.451	5.7		3.51
45	4.50	0.442	4.57		3.26
50	3.72	0.435	3.75		3.00
60	2.65	0.424	2.74		2.60
70	2.04	0.415	2.23		2.30
80	1.68	0.407	1.95		2.09
90	1.46	0.401	1.78		1.92
100	1.32	0.396	1.69		1.79
200	0.94	0.366	1.59		1.43
273	0.835	0.355	1.57	(0.078)	1.39
300	0.803	0.352	1.56	(0.084)	1.38
400	0.694	0.338	1.53	(0.098)	1.34
500	0.613	0.325	1.51	(0.109)	1.3
600	0.547	0.312	1.49	(0.12)	1.26
700	0.487	(0.174)	1.47	(0.127)	1.22
800	0.433	(0.19)	1.46	(0.13)	1.18
900	0.38	(0.203)	1.45		1.15
1000	0.326	(0.215)	(0.84)		1.12
1100	0.297		(0.91)		1.08
1200	0.282		(0.98)		1.05
1400	0.309				0.996
1600	0.327				0.946
1800					0.907
2000					0.88
2200					0.858
2600					0.825

Thermal Conductivity of Metals (Part 2) (continued)

Values are in watt · cm^{-1} · K^{-1}.

Note: Values in parentheses are for liquid state.

These data apply only to metals of purity of at least 99.9%.

The third significant figure may not be accurate.

From Shackelford, J.F. and Alexander, W., *CRC Handbook of Materials Science and Engineering*, CRC Press, Boca Raton, FL, 2001, pp. 386–387.

Thermal Conductivity of Metals (Part 3)

T (K)	Nickel	Niobium	Platinum	Silver	Tantalum
1	0.64	0.251	2.31	39.4	0.115
2	1.27	0.501	4.60	78.3	0.230
3	1.91	0.749	6.79	115	0.345
4	2.54	0.993	8.8	147	0.459
5	3.16	1.23	10.5	172	0.571
6	3.77	1.46	11.8	187	0.681
7	4.36	1.67	12.6	193	0.788
8	4.94	1.86	12.9	190	0.891
9	5.49	2.04	12.8	181	0.989
10	6.00	2.18	12.3	168	1.08
11	6.48	2.30	11.7	154	1.16
12	6.91	2.39	10.9	139	1.24
13	7.30	2.46	10.1	124	1.30
14	7.64	2.49	9.3	109	1.36
15	7.92	2.50	8.4	96	1.40
16	8.15	2.49	7.6	85	1.44
18	8.45	2.42	6.1	66	1.47
20	8.56	2.29	4.9	51	1.47
25	8.15	1.87	3.15	29.5	1.36
30	6.95	1.45	2.28	19.3	1.16
35	5.62	1.16	1.80	13.7	0.99
40	4.63	0.97	1.51	10.5	0.87
45	3.91	0.84	1.32	8.4	0.78
50	3.36	0.76	1.18	7.0	0.72
60	2.63	0.66	1.01	5.5	0.651
70	2.21	0.61	0.90	4.97	0.616
80	1.93	0.58	0.84	4.71	0.603
90	1.72	0.563	0.81	4.60	0.596
100	1.58	0.552	0.79	4.50	0.592
200	1.06	0.526	0.748	4.3	0.575
273	0.94	0.533	0.734	4.28	0.574
300	0.905	0.537	0.73	4.27	0.575
400	0.801	0.552	0.722	4.2	0.578
500	0.721	0.567	0.719	4.13	0.582
600	0.655	0.582	0.72	4.05	0.586
700	0.653	0.598	0.723	3.97	0.59
800	0.674	0.613	0.729	3.89	0.594

Thermal Conductivity of Metals (Part 3) (continued)

T (K)	Nickel	Niobium	Platinum	Silver	Tantalum
900	0.696	0.629	0.737	3.82	0.598
1000	0.718	0.644	0.748	3.74	0.602
1100	0.739	0.659	0.76	3.66	0.606
1200	0.761	0.675	0.775	3.58	0.610
1400	0.804	0.705	0.807		0.618
1600		0.735	0.842		0.626
1800		0.764	0.877		0.634
2000		0.791	0.913		0.640
2200		0.815			0.647
2600					0.658
3000					0.665

From Shackelford, J.F. and Alexander, W., *CRC Handbook of Materials Science and Engineering*, CRC Press, Boca Raton, FL, 2001, pp. 388–389.

Thermal Conductivity of Metals (Part 4)

T (K)	Tin	Titanium	Tungsten	Zinc	Zirconium
1		0.0144	14.4	19.0	0.111
2		0.0288	28.7	37.9	0.223
3	297	0.0432	42.6	55.5	0.333
4	181	0.0576	55.6	69.7	0.442
5	117	0.0719	67.1	77.8	0.549
6	76	0.0863	76.2	78.0	0.652
7	52	0.101	82.4	71.7	0.748
8	36	0.115	85.3	61.8	0.837
9	26	0.129	85.1	51.9	0.916
10	19.3	0.144	82.4	43.2	0.984
11	14.8	0.158	77.9	36.4	1.04
12	11.6	0.172	72.4	30.8	1.08
13	9.3	0.186	66.4	26.1	1.11
14	7.6	0.200	60.4	22.4	1.13
15	6.3	0.214	54.8	19.4	1.13
16	5.3	0.227	49.3	16.9	1.12
18	4.0	0.254	40.0	13.3	1.08
20	3.2	0.279	32.6	10.7	1.01
25	2.22	0.337	20.4	6.9	0.85
30	1.76	0.382	13.1	4.9	0.74
35	1.50	0.411	8.9	3.72	0.65
40	1.35	0.422	6.5	2.97	0.58
45	1.23	0.416	5.07	2.48	0.535
50	1.15	0.401	4.17	2.13	0.497
60	1.04	0.377	3.18	1.71	0.442
70	0.96	0.356	2.76	1.48	0.403
80	0.91	0.339	2.56	1.38	0.373
90	0.88	0.324	2.44	1.34	0.350
100	0.85	0.312	2.35	1.32	0.332

Thermal Conductivity of Metals (Part 4) (continued)

T (K)	Tin	Titanium	Tungsten	Zinc	Zirconium
200	0.733	0.245	1.97	1.26	0.252
273	0.682	0.224	1.82	1.22	0.232
300	0.666	0.219	1.78	1.21	0.227
400	0.622	0.204	1.62	1.16	0.216
500	0.596	0.197	1.49	1.11	0.210
600	(0.323)	0.194	1.39	1.05	0.207
700	(0.343)	0.194	1.33	(0.499)	0.209
800	(0.364)	0.197	1.28	(0.557)	0.216
900	(0.384)	0.202	1.24	(0.615)	0.226
1000	(0.405)	0.207	1.21	(0.673)	0.237
1100	(0.425)	0.213	1.18	(0.73)	0.248
1200	(0.446)	0.220	1.15		0.257
1400	(0.487)	0.236	1.11		0.275
1600		0.253	1.07		0.290
1800		0.271	1.03		0.302
2000			1.00		0.313
2200			0.98		
2600			0.94		
3000			0.915		

Values are in watt · cm^{-1} · K^{-1}.

Note: Values in parentheses are for liquid state.

These data apply only to metals of purity of at least 99.9%.

The third significant figure may not be accurate.

From Shackelford, J.F. and Alexander, W., *CRC Handbook of Materials Science and Engineering*, CRC Press, Boca Raton, FL, 2001, pp. 390–391.

General Properties of Refrigerants*

	R-11	R-12	R-13	R-22	R-113	R-114	R-500	R-502	R-717
Chemical formula	CCl_3F	CCl_2F_3	$CClF_3$	$CHClF_2$	$CCl_2F\text{-}CClF_2$	$C_2Cl_2F_4$	‡	**	NH_3
Molecular weight	137.38	120.93	104.47	86.48	187.39	170.94	99.31	111.6	17.03
Boiling temperature at 14.7 psia, °F	74.9	–21.6	–114.6	–41.4	117.6	38.8	–28.3	–50.1	–28.0
Freezing temperature at 14.7 psia, °F	–168	–252	–294	–256	–31	–137	–254	—	–108
Critical temperature, °F	388.4	233.6	83.9	204.8	417.4	294.3	221.9	194	271.4
Critical pressure, psia	640	597	561	721.9	498.9	473	641.9	619	1 657
Critical pressure, MN/m²	4.41	4.12	3.87	4.98	3.44	3.26	4.43	4.27	11.4
Critical density, lb/cu ft	34.6	34.84	36.1	32.8	36.0	36.3	31.0	34.91	14.6
Critical density, kg/m³	554	558	578	525	577	581	496	559	234
Density of liquid, 86°F, lb/cu ft	91.39	80.67	81.05^{-22}	73.28	96.96	89.95	71.06	76.13	37.16
Density of liquid, 303.15 K, kg/m³	1 464	1 292	$1\ 298^{-22}$	1 174	1 553	1 441	1 138	1 219	595.2
Sp vol of sat bvapor, 5°F, cu ft/lb	12.205	1.458	0.304	1.243	27.04	4.226	1.501	0.825	8.150
Sp vol of sat vapor, 258.15 K, m³/kg	0.7619	0.091 02	0.018 98	0.077 60	1.688	0.263 8	0.093 7	0.051 50	0.508 8
Sp heat of liquid, 86°F, Btu/lb °F	0.21	0.235	0.247	0.305	0.218	0.246	0.290	0.305	1.14
Sp heat of liquid, 303.15 K, kJ/kg·K	0.878	0.983	1.03	1.28	0.912	1.03	1.21	1.28	4.77
Sp heat ratio (c_p/c_v); vapor at 86°F and 14.7 psia	1.13	1.139	1.17	1.18	1.12	1.09	1.14	1.135	1.29
Thermal conductivity									
Sat liquid, 5°F	0.058	0.052	0.06^{-95}	0.069	0.044	0.041		0.052	0.29
Sat liquid, 258.15 K	100	90	100^{-95}	120	76	71		90	500
Sat liquid, 86°F	0.049	0.040		0.050	0.037	0.033		0.037	0.29
Sat liquid, 303.15 K	85	69		86	64	57		64	500
Vapor at sat press, 5°F	0.003 4	0.004 7		0.005 1	0.003 5	0.004 7		0.005 4	0.012
Vapor at sat press, 258.15 K	5.9	8.1		8.8	6.0	8.1		9.3	21
Vapor at 14.7 psia, 86°F	0.004 5	0.005 9		0.006 5	0.004 5	0.0065 2		0.006 9	0.014
Vapor at 0.101 3 MN/m², 303.15 K	7.8	10		11	7.8	11		12	24
Viscosity, N·s/m²									
Sat liquid, 5°F	0.630	0.335	$.037^{-95}$	0.298	1.28	0.614	0.292	0.334	0.250
Sat liquid, 258.15 K	0.000 630	0.000 335	$0.000\ 037^{-95}$	0.000 298	0.001 28	0.000 614	0.000 292	0.000 334	0.000 2
Sat liquid, 86°F	0.404	0.254		0.230	0.638	0.356	0.220	0.240	0.207
Sat liquid, 303.15 K	0.000 404	0.000 254		0.000 230	0.000 638	0.000 356	0.000 220	0.000 240	0.000 2
Vapor at sat press, 5°F	0.008 7	0.010 8		0.011 2	0.007 9	0.009 6		0.011 2	0.008 5
Vapor at sat press, 258.15 K	0.000 008 7	0.000 010 8		0.000 011 2	0.000 007 9	0.000 009 6		0.000 011 2	0.000 000
Vapor at 14.7 psia, 86°F	0.010 8	0.012 7		0.013 2	0.009 6	0.011 4		0.013 1	0.010 2
Vapor at 0.101 3 MN/m², 303.15 K	0.000 010 8	0.000 012 7		0.000 012 3	0.000 009 6	0.000 011 4		0.000 013 1	0.000 00
Relative dielectric strength of vapor at 73°F and 14.7 psia (nitrogen = 1)	3.1	2.4	1.4	1.3	3.9				0.82 (84°F)

Toxicity Underwriters' Laboratories Classification†	Group 5a	Group 6	Group 6+	Group 5a	Group 4 1/2	Group 6	Group 5a	Group 5a

† See explanation at end of table.
‡ R-500 is azeotrope 73.8% (by wt) CCl_2F_2 and 26.2% (by wt) CH_3-CHF_2.
** R-502 is azeotrope $CHClF_2$ = 48.8% and $CClF_2CF_3$ = 51.2%.

Property	Fluorocarbons R-13B1	Fluorocarbons R-14	R-40, Methyl Chloride	R-50, Methane	R-170, Ethane	R-290, Propane	R-600, n-Butane	R-744, Carbon Dioxide
Chemical formula	$CBrF_3$	CF_4	CH_3Cl	CH_4	C_2H_6	C_3H_8	C_4H_{10}	CO_2
Molecular weight	148.9	88.01	50.48	16.03	30.04	44.09	58.12	44.01
Boiling point at 14.7 psia, °F	–72.0	–198.4	–10.8	–258.9	–127.5	–44.2	31.3	–109.3 subl.
Freezing point at 14.7 psia, °F	–270	–299	–144	–297	–278	–309.8	–217	–69.9[a]
Critical temperature, °F	152.6	–50	289.4	–115.8	90.1	206	306	87.8
Critical pressure, psia	575	543	968.7	673.1	708.3	617.4	550.1	1057.4
Critical pressure, MN/m^2	3.96	3.74	6.68	4.64	4.88	4.26	3.79	7.29
Critical density, lb/cu ft	46.5	39	23.3	10.1	13.2	13.7	14.2	28.6
Critical density, kg/m^3	745	625	373	162	211	219	227	458
Density of liquid, 86°F, lb/cu ft	93.58	82.2[b]	56.24		16.57	36.2	35.62	
Density of liquid, 303.15 K, kg/m^3	1 499	1 317[b]	900.9		265.4	579.9	570.6	
Sp vol of sat vapor, 5°F, cu ft/lb	0.379 6		4.471		0.531 3	2.509	9.98	0.266 1
Sp vol of sat vapor, 258.15 K, m^3/kg	0.023 70		0.279 1		0.033 17	0.156 6	0.623 0	0.016 61
Toxicity (Underwriters' Laboratories Classification)[d]	Group 6	Group 6[c]	Group 4	Group 5[a]	Group 5[a]	Group 5[a]	Group 5	Group 5

[a] At 76.4 psia.
[b] At –112°F (317.59 K).
[c] Unofficial.
[d] The Underwriters' Laboratories Classification of toxicity is as follows:

Group 1: Lethal concentration 0.5 to 1.0 percent for durations of 5 minutes.
Group 2: Lethal concentration 0.5 to 1.0 percent for durations of 30 minutes.
Group 3: Lethal concentration 2.0 to 2.5 percent for durations of 1 hour.
Group 4: Lethal concentration 2.0 to 2.5 percent for durations of 2 hours.
Group 5a: Less toxic than group 4, more toxic than group 6.
Group 5b: Available data would classify these as 5a or 6.
Group 6: Concentrations up to about 20 percent for 2 hours do not appear to produce injury.

* Based largely on: "ASHRAE Handbook of Fundamentals," American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1972.

Reference

"Properties of Commonly-Used Refrigerants," Air-Conditioning Refrigeration Institute, 1967.

From Bolz, R.E. and Tuve, G.L., Gases and vapors, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, pp. 68–69.

Thermodynamic Properties of Saturated Mercury

Enthalpy and Entropy Measured from 32°F

For pressures in MN/m^2, multiply value in lbf/in.^{2} by 0.006 894 8. For temperature in K, add 459.67 to value in deg F and multiply he result by 5/9. For enthalpy in J/kg, multiplying value in Btu/lb by 2 324.4. For entropy in J/kg·K, multiply value in Btu/lb·deg F by 4 186.8. For specific volume in m^3/kg. Multiply value in ft^3/lb_m by 0.062 420.

		Enthalpy, Btu/lb_m			Entropy, Btu/lb_m°R			Specific Volume,
Pressure $lb_f/in.^2$	Temperature, °F	Saturated Liquid	Evaporation	Saturated Vapor	Saturated Liquid	Evaporation	Saturated Vapor	Sat Vapor, ft^3/lb_m
0.020	259.9	7.532	127.614	135.146	0.01259	0.17735	0.18994	1893
0.040	288.3	8.463	127.486	135.949	0.01386	0.17044	0.18430	986
0.075	316.2	9.373	127.361	136.734	0.01504	0.16415	0.17919	545
0.100	329.7	9.814	127.300	137.114	0.01561	0.16126	0.17687	416
0.200	364.3	10.936	127.144	138.080	0.01699	0.15432	0.17131	217.3
0.400	402.0	12.159	126.975	139.134	0.01844	0.14736	0.16580	113.7
0.600	425.8	12.929	126.868	139.797	0.01932	0.14328	0.16260	77.84
0.800	443.5	13.500	126.788	140.288	0.01994	0.14038	0.16032	59.58
1.00	457.7	13.959	126.724	140.683	0.02045	0.13814	0.15859	48.42
2.00	504.9	15.476	126.512	141.988	0.02205	0.13116	0.15321	25.39
4.00	557.9	17.161	126.275	143.436	0.02373	0.12434	0.14787	13.38
6.00	591.2	18.233	126.124	144.357	0.02477	0.12002	0.14479	9.26
8.00	616.5	19.035	126.011	145.046	0.02551	0.11712	0.14264	7.12
10	637.0	19.685	125.919	145.604	0.02610	0.11483	0.14093	5.81
20	706.0	21.864	125.609	147.473	0.02800	0.10779	0.13579	3.09
40	784.4	24.345	125.255	149.600	0.03004	0.10068	0.13072	1.648
60	835.7	25.940	125.024	150.964	0.03127	0.19652	0.12779	1.144
80	874.8	27.159	124.849	152.008	0.03218	0.09356	0.12574	0.885
100	906.8	28.152	124.706	152.858	0.03290	0.09127	0.12417	0.725
120	934.3	29.005	124.582	153.587	0.03350	0.08938	0.12288	0.617
140	958.3	29.748	124.474	154.222	0.03401	0.08778	0.12179	0.538
160	979.9	30.415	124.376	154.791	0.03447	0.08640	0.12087	0.478
180	999.5	31.018	124.288	155.306	0.03488	0.08518	0.12006	0.431
200	1017.2	31.560	124.209	155.769	0.03523	0.08411	0.11934	0.392
225	1038.0	32.204	124.115	156.319	0.03565	0.08287	0.11852	0.354
250	1057.2	32.784	124.029	156.813	0.03603	0.08178	0.11871	0.322
275	1074.8	33.322	123.950	157.272	0.03637	0.08079	0.11716	0.297
300	1091.2	33.824	123.876	157.700	0.03669	0.07989	0.11658	0.276
350	1121.4	34.747	123.740	158.487	0.03725	0.07828	0.11553	0.241
400	1148.4	35.565	123.620	159.185	0.03775	0.07688	0.11463	0.215
500	1196.0	37.006	123.406	160.412	0.03861	0.07455	0.11316	0.177
600	1236.8	38.245	123.221	161.466	0.03932	0.07264	0.11196	0.151
800	1306.1	40.324	122.910	163.234	0.04047	0.06961	0.11008	0.118
1000	1364.0	42.056	122.649	164.705	0.04139	0.06726	0.10865	0.098
1100	1390.0	42.828	122.533	165.361	0.04179	0.06625	0.10804	0.090

From Bolz, R.E. and Tuve, G.L., Gases and vapors, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 87. Originally abridged from "Thermodynamic Properties of Mercury Vapor," by L.A. Sheldon. Courtesy of General Electric Company.

Properties of Rare-Earth Metals

To convert density from g/cm³ to kg/m³, multiply by 1000. To convert Young's modulus from kg/cm² to N/m², multiply by 98,067. Values in parentheses are estimates.

Element	Melting Point, °C	Boiling Point, °C	Heat of Sublimation, kcal/mole ΔH 298°K	Density, g/cm³ 298°K	Atomic Volume, cm³/mole	Metallic Radius, Å	Electrical Restivity at 298°K, microhm-cm	Residual Resistivity at 4.2°K, microhm-cm	Compresibility, cm²/kg†	Young's Modulus kg/cm², Millions	Poisson's Ratio
Scandium	1539	2832	91.0	2.989	15.04	1.641	50.9	3.7	2.26	0.809	(0.269)
Yttrium	1523	3337	99.6	4.457	19.95	1.803	59.6	3.2	2.68	0.663	0.265
Lanthanum	920	3454	103.0	6.166	22.53	1.877	79.8	S.C.‡	4.04	0.384	0.288
Cerium	798	3257	111.60	6.771	20.69	1.824	75.3		4.10	0.306	0.248
Praseodymium	931	3212	89.09	6.772	20.81	1.828	68.0	0.7	3.21	0.332	0.305
Neodymium	1010	3127	77.3	7.003	20.60	1.822	64.3	6.8	3.0	0.387	0.306
Promethium	1080	(2460)	(64)	—	—	—	—	—	(2.8)	(0.430)	(0.278)
Samarium	1072	1778	49.3	7.537	19.95	1.802	105.0	6.2	3.34	0.348	0.352
Europium	822	1597	42.5	5.253	28.93	1.983	91.0	0.6	8.29	0.150	(0.286)
Gradolinium	1311	3233	95.75	7.898	19.91	1.801	131.0	4.4	2.56	0.573	0.259
Terbium	1360	3041	93.96	8.234	19.30	1.783	114.5	3.5	2.45	0.586	0.261
Dysprosium	1409	2335	71.2	8.540	19.03	1.775	92.6	2.4	2.55	0.644	0.243
Holmium	1470	2720	71.7	8.781	18.78	1.767	81.4	7.0	2.47	0.684	0.255
Erbium	1522	2510	74.5	9.045	18.49	1.758	86.0	4.7	2.39	0.748	0.238
Thulium	1545	1727	58.3	9.314	18.14	1.747	67.6	5.6	2.47	(0.770)	(0.235)
Ytterbium	824	1193	38.2	6.972	24.82	1.939	25.1	0.29	7.39	0.182	0.284
Lutertium	1656	3315	102.16	9.835	17.79	1.735	58.2	4.5	2.38	(0.860)	(0.233)

† All values in this column should be divided by 10^6.

‡ S.C.–Superconductor.

From Spedding, F.H., Solids — Metals, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 129.

Products of Powder Metallurgy

Powder metallurgy refers to the production of parts by a process of molding metal powders and agglomerating the form by heat. The powder mixture is often hot-molded under pressure (10,000–10,000 psi) and is sintered in an inert or a reducing atmosphere, at a temperature between 400–2,000 deg F, depending on the metal mixture. For the refractory metals higher temperatures are necessary. The methods of powder metallurgy provide a close control of the composition and allow use of mixtures that could not be fabricated by any other process. As dimensions are determined by the mold, finish machining or grinding is often eliminated, thereby reducing cost and handling, especially for large lots. Special properties of the finished product, such as porosity, friction coefficient, and electrical conductivity, can be varied somewhat by changing the proportions of the powder components.

Class	Composition or Constituents	Applications and Uses	Desirable Properties and Advantages
Small, finished parts	Various ferrous, copper, and nickel alloys	Complex shapes; small parts not requiring high strength or ductility; plain bearings	Control of dimensions and finish; two-phase bearing metals; low cost in large production lots
Refractory metals	Pure W, Mo, Ta, Nb, Re, Ti alloys	Production of high-purity tungsten, molybdenum, tantalum, niobium, etc.; beryllium; cobalt alloys	Metals used in high-temperature service; electrical, electronic, and nuclear applications
Porous metals	Copper; copper-lead; bronze; stainless steel	Porous bearings, oil-impregnated, or with graphite or plastic; friction materials; metal filters; porous electrodes; catalysts; throttle plates	Interconnected pores in the size range 5–50 microns; porosity about 20–30%
Composite metals	Al, Cu, etc. with W, Mo, Co, or stainless steel reinforcing; reactor fuel elements	Services requiring high strength with lightness, high electrical and thermal conductivities; nuclear reactor components	High-strength materials from common metals; durability of nuclear materials
Metal–nonmetal composites	Filament-reinforced ceramics; dispersion strengthening by oxides	Ceramics with good structural properties; lightweight materials for high temperature (e.g., SAP)	Strengthened ceramics; heat-resistant aluminum
Magnetic materials	Nickel-iron; cobalt mixtures; ferrites	High-permeability materials; permanent magnets; ferrite cores; magnetic storage	Very high magnetic properties and close control of magnetic properties
Cermets, oxide	Al_2O_3-Cr; Al_2O_3-Cr-W; Al_2O_3-Cr-Mo; ThO_2-W	Combustion and rocket nozzles; furnace muffler, tubes, seals, extrusion dies; power-tube cathodes	High-temperature strength (2,000 deg F and above); resistance to thermal shock; high thermal conductivity; corrosion resistance
Cermets, carbide	TiC-Ni; TiC-Fe-Cr; TiC-Co-Cr-W; Cr_3C_2-Ni-W	High-temperature bearings, seals, and dies; gage blocks	Strength toughness, and corrosion resistance at high temperatures (to 1,700 deg F); hardness
Cemented carbides	WC-Co; WC-TaC-Co; TiC-Ni; Cr_3C_2-WC-Ni	Tips for cutting tools, lathe centers, gages; wire-drawing dies; rock drills; crushers; blast nozzles	Very high hardness, compressive strength, and elastic modulus; war and corrosion resistance; high conductivity; high-temperature strength

From Bolz, R.E. and Tuve, G.L., Solids — Metals, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 133.

Fiber-Reinforced Metals

Ductile and low-strength metals have been reinforced with various fibers. Fiber bundles or mats in molten metals, powder mixtures pressed or extruded, and electroplating are some of the fabrication methods. Copper, aluminum, silver, nickel and titanium are among the matrix materials, with reinforcement by steel, tungsten, boron, molybdenum, silica, glass, oxides, and carbides. The ratio of fiber-strength/matrix-strength determines a certain minimum fiber volume for effective reinforcement, but the fiber–matrix bond and fiber-to-stress alignment are also critical. Increase of strength is almost linear with fiber volume. Short fibers are not fully effective so that the strength is increased much less for a given fiber-volume fraction. Typical test results for fiber-reinforced metals are included in the following table.

Test Results on Composite Metals*

Matrix Metals	Strengthener: Component	Strengthener: % vol	Stress, kpsi: Matrix Only, No Reinforcement	Stress, kpsi: Composite Material
		Metals Strengthened by Fibers		
Copper	W fibers	60	20	200[a]
Silver	Al_2O_3 whiskers	35	10[b]	75[b]
Aluminum	Glass fibers	50	(23%)[c]	(94%)[c]
Aluminum	Al_2O_3	35	25[d]	161[d]
Aluminum	Steel	25	25[d]	173[d]
Nickel	B	8	70[d]	384[d]
Iron	Al_2O_3	36	40[d]	237[d]
Titanium	Mo	20	80[d]	96[d]
		Metals Strengthened by Sintered Carbides		
Cobalt	WC	90	(E = 30)[e]	(E = 85)[e]
Nickel	TiC	75	(E = 31)[f]	(E = 55)[f]

[a] Tensile strength with continuous fibers.
[b] Tensile strength at 350 deg C; modulus of elasticity: Cu = 17, composite 42 (millions of psi).
[c] Percentage of tensile strength at room temperature retained when tested at 300 deg C.
[d] Tensile strength, room temperature.
[e] Modulus of elasticity, *E*, measured in compression; hardness, 90 R-A; compressive strength, about 600,000 psi.
[f] Modulus of elasticity, *E*, measured in compression; hardness about 85 R-A.
* Compiled from various sources.

References

"Metals Handbook: Properties and Selection," Vol. 1, American Society for Metals, 1961.

"Modern Composite Materials," L.J. Broutman and R.H. Krock, Addison-Wesley Publishing Company, 1967.

From Bolz, R.E. and Tuve, G.L., Solids — Metals, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 135.

Properties of Commercial Plastics

Of the many plastics commercially available in each chemical class, only one or a very few examples have been selected for this table as typical of the class. In some cases the range or properties have been expanded to include several grades or types. It is impractical to include a comprehensive list of materials or known properties of these materials in a table of convenient size. Properties vary widely with amount and kind of modifier, such as filler and plasticizer. Within any type of thermoplastic resins, molecular weight is an important variable. This property is controlled to afford the best physical properties available consistent with economical processing properties.

The information shown refers in all cases, except for “Forms available” and “Fabrication,” to material in the fabricated form, which in the case of thermosetting materials means commercially cured. Physical and electrical properties will vary, to a greater or lesser degree, with different materials, with humidity conditioning environment and with orientation. Strength values are quoted on the basis of short-time tests at normal room temperature and are not suitable for engineering design purposes for load-bearing applications. Maximum continuous service temperature refers to unloaded structures. The user of this table is referred to the specifications and test procedures of the American Society for Testing Materials.

To convert psi to N/m^2, multiply by 6,895. For specific heat in J/kg·K, multiply by 4,184.

	Chemical Class	Cellulose Acetate	Cellulose Acetate	Cellulose Acetate Butyrate
	Resin Type	Thermoplastic	Thermoplastic	Thermoplastic
Properties	Subclass or Modification	Soft	Hard	Soft
Electrical Properties				
D.C. resistivity, ohm-cm		10^{10}–10^{13}	10^{10}–10^{13}	10^{10}–10^{12}
Dielectric constant, 60 cps		3.5–7.5	3.5–7.5	3.5–6.4
Dielectric constant, 10^6 cps		3.2–7.0	3.2–7.0	3.2–6.2
Dissipation factor, 60 cps		0.01–0.06	0.01–0.06	0.01–0.04
Dissipation factor, 10^6 cps		0.01–0.10	0.01–0.10	0.01–0.04
Mechanical Properties				
Modulus of elasticity, 10^3 psi		86–250	190–400	74–126
Tensile strength, psi		1,900–4,700	4,600–8,500	1,900–3,800
Ultimate elongation, %		32–50	6–40	60–74
Yield stress, psi		2,200–4,200	4,100–7,600	1,200–2,600
Yield strain, %				
Rockwell hardness		R 49–R 103	R 101–R 123	R 59–R 95
Notched Izod impact strength, ft lb/in.		2.0–5.2	0.4–2.7	2.5–5.4
Specific gravity		1.27–1.34	1.27–1.34	1.15–1.22
Thermal Properties				
Burning rate		Medium	Medium	Medium
Heat distortion, 264 psi, °C		44–57	60–113	49–58
Specific heat, cal/g		0.3–0.42	0.3–0.42	0.3–0.4
Linear thermal expansion coefficient, 10^{-5}, °C		8–16	8–16	11–17
Maximum continuous service temperature, °C				
Chemical Resistance				
Mineral acids, weak		Fair to good	Fair to good	Good
Mineral acids, strong		Poor	Poor	Fair to good
Oxidizing acids, concentrated		Very poor	Very poor	
Alkalies, weak		Poor	Poor	Good
Alkalies, strong		Very poor	Very poor	Poor
Alcohols		Poor	Poor	Poor
Ketones		Poor	Poor	Poor
Esters		Poor	Poor	Poor
Hydrocarbons, aliphatic		Fair to good	Fair to good	Fair to good
Hydrocarbons, aromatic		Poor to fair	Poor to fair	Poor
Oils: vegetable, animal, mineral		Fair to good	Fair to good	Good
Miscellaneous Properties				
Clarity		Excellent	Excellent	Good to excellent
Color		Pale to colorless	Pale to colorless	Pale to colorless
Refractive index, n_D		1.46–1.50	1.46–1.50	1.46–1.49
Application ASTM specifications and test methods		D786, D706, D257, D150, D638, D785, D256, D792, D648, D696, D543, D542	D786, D706, D257, D150, D638, D785, D256, D792, D648, D696, D543, D542	D707, D257, D150, D638, D785, D256, D792, D648, D696

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.	F, Lq, P, R, S	F, Lq, P, R, S	F, Lq, P, R, S
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.	Cs, E, F, MB, MC, MI, S	Cs, E, F, MB, MC, MI, S	Cs, E, F, MB, MC, MI, S

Properties	Chemical Class	Cellulose Acetate Butyrate	Nylon	Polycarbonates
	Resin Type	Thermoplastic	Thermoplastic	Thermoplastic
	Subclass or Modification	Hard	6/6	Unfilled
Electrical Properties				
D.C. resistivity, ohm-cm		10^{10}–10^{12}		2×10^{16}
Dielectric constant, 60 cps		3.5–6.4	4.0–4.6	3.17
Dielectric constant, 10^6 cps		3.2–6.2	3.4–3.6	2.96
Dissipation factor, 60 cps		0.01–0.04	0.014–.04	0.0009
Dissipation factor, 10^6 cps		0.01–0.04	0.04	0.001
Mechanical Properties				
Modulus of elasticity, 10^3 psi		150–200		290–325
Tensile strength, psi		5,000–6,800	9,000–12,000	8,000–-9,500
Ultimate elongation, %		38–54	60–300	20–100
Yield stress, psi		3,600–6,100		8,000–10,000
Yield strain, %				
Rockwell hardness		R 108–R 117	R 108–R 120	M 70–M 180
Notched Izod impact strength, ft lb/in.		0.7–2.4	1.0–2.0	8–16
Specific gravity		1.19–1.25	1.13–1.15	1.2
Thermal Properties				
Burning rate		Medium	Self-extinguishing	Self-extinguishing
Heat distortion, 264 psi, ˚C		70–99		135–145
Specific heat, cal/g		0.3–0.4	0.4	0.3
Linear thermal expansion coefficient, 10^{-5}, ˚C		11–17	8.0	6.6
Maximum continuous service temperature, ˚C			80–150	138–143
Chemical Resistance				
Mineral acids, weak		Good	Very good	Excellent
Mineral acids, strong		Fair to good	Poor	Fair
Oxidizing acids, concentrated			Poor	
Alkalies, weak		Good	No effect	Poor
Alkalies, strong		Poor	No effect	Poor
Alcohols		Poor	Good	Poor
Ketones		Poor	Good	Poor
Esters		Poor	Good	Poor
Hydrocarbons, aliphatic		Fair to good	Very good	Poor
Hydrocarbons, aromatic		Poor	Fair to good	Poor
Oils: vegetable, animal, mineral		Good	Good	Poor
Miscellaneous Properties				
Clarity		Good to excellent	Clear	Clear
Color		Pale to colorless	Pale amber to colorless	Colorless
Refractive index, n_D		1.46–1.49	1.53	1.60
Application ASTM specifications and test methods		D707, D257, D150, D256, D792, D648, D542, D638, D785, D696, D543	D257, D150, D638, D792, D648, D696, D785, D256, D542, D543	D257, D150, D638, D792, D648, D696, D785, D256, D542, D543

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.	F, Lq, P, R, S	F, Fb, Mf, P, R, S	F, Fb, Mf, P, R, S
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.	Cs, E, F, MB, MC, MI, S	E, F, MB, MC, MI	Cs, E, F, MB, MC, MI

To convert psi to N/m^2, multiply by 6,895. For specific heat in J/kg·K, multiply by 4,184.

Properties	Chemical Class	Polyethylene	Polyethylene	Polyethylene
	Resin Type	Thermoplastic	Thermoplastic	Thermoplastic
	Subclass or Modification	Low Density	Medium Density	High Density
Electrical Properties				
D.C. resistivity, ohm-cm		$>10^{15}$	$>10^{15}$	$>10^{15}$
Dielectric constant, 60 cps		2.3–2.35	2.3	2.3–2.35
Dielectric constant, 10^6 cps		2.3–2.35	2.3	2.3–2.35
Dissipation factor, 60 cps		<0.0005	<0.0005	<0.0005
Dissipation factor, 10^6 cps		<0.0005	<0.0005	<0.0005
Mechanical Properties				
Modulus of elasticity, 10^3 psi		14–38	35–90	85–160
Tensile strength, psi		1,000–1,400	1,200–3,500	3,100–5,500
Ultimate elongation, %		400–700	50–600	15–100
Yield stress, psi		1,100–1,700	1,500–2,600	2,400–5,000
Yield strain, %		20–40	10–20	5–10
Rockwell hardness				R 30–R 50
Notched Izod impact strength, ft lb/in.		No break	0.5–>16	1.5–20
Specific gravity		0.91–0.925	0.926–0.941	0.941–0.965
Thermal Properties				
Burning rate		Very slow	Slow	Slow
Heat distortion, 264 psi, °C				
Specific heat, cal/g		0.55	0.55	0.55
Linear thermal expansion coefficient, 10^{-5}, °C		10–20	14.16	11.13
Maximum continuous service temperature, °C		60–77	71–93	92–200
Chemical Resistance				
Mineral acids, weak		Good	Excellent	Excellent
Mineral acids, strong		Good	Excellent	Excellent
Oxidizing acids, concentrated		Good to poor	Good to poor	Good to poor
Alkalies, weak		Good	Excellent	Excellent
Alkalies, strong		Good	Excellent	Excellent
Alcohols		Excellent to poor	Excellent to poor	Excellent to poor
Ketones		Excellent to poor	Excellent to poor	Excellent to poor
Esters		Excellent to poor	Excellent to poor	Excellent to poor
Hydrocarbons, aliphatic		Fair	Fair	Fair
Hydrocarbons, aromatic		Fair	Good	Fair
Oils: vegetable, animal, mineral		Good	Excellent	Good
Miscellaneous Properties				
Clarity		Translucent	Translucent	Translucent
Color		Colorless	Colorless	Colorless
Refractive index, n_D		1.50–1.54	1.52–1.54	1.54
Application ASTM specifications and test methods		D702, D788, D257, D638, D696, D543, D150, D412, D1248, D542	D257, D150, D412, D256, D696, D543, D638, D785, D1248, D542	D257, D150, D412, D256, D696, D543, D638, D785, D1248, D542

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.		F, Mf, P, R, S	F, Mf, P, R, S	F, Fb, Mf, P, R, S
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.		Cl, E, F, MB, MC, MI	Cl, E, F, MB, MC, MI	Cl, E, F, MB, MC, MI
	Chemical Class	Methylmethacrylate	Polypropylene	Polypropylene
	Resin Type	Thermoplastic	Thermoplastic	Thermoplastic
Properties	Subclass or Modification	Unmodified	Unmodified	Unmodified
Electrical Properties				
D.C. resistivity, ohm-cm		$>10^{14}$	$>10^{15}$	$>10^{17}$
Dielectric constant, 60 cps		3.5–4.5	2.2–2.6	2.3
Dielectric constant, 10^6 cps		3.0–3.5	2.2–2.6	2.3
Dissipation factor, 60 cps		0.04–0.06	<0.0005	0.0001–0.0005
Dissipation factor, 10^6 cps		0.02–0.03	0.0005–0.002	0.0001–0.002
Mechanical Properties				
Modulus of elasticity, 10^3 psi		350–500	1.4–1.7	
Tensile strength, psi		7,000–11,000	4,300–5,500	2,900–4,500
Ultimate elongation, %		2.0–1.0	>220	200–700
Yield stress, psi			4,900	
Yield strain, %			15	
Rockwell hardness		M 80–M 105	93	R 30–R 96
Notched Izod impact strength, ft lb/in.		0.3–0.6	1.0	1.1–12
Specific gravity		1.18–1.20	0.90	0.90
Thermal Properties				
Burning rate		Slow	Medium	Medium
Heat distortion, 264 psi, °C		66–99		
Specific heat, cal/g		0.35	0.5	0.5
Linear thermal expansion coefficient, 10^{-5}, °C		5.0–9.0	5.8–10	8–10
Maximum continuous service temperature, °C		60–93		190–240
Chemical Resistance				
Mineral acids, weak		Good	Excellent	Excellent
Mineral acids, strong		Fair to poor	Excellent	Excellent
Oxidizing acids, concentrated		Attacked	Good to poor	Poor
Alkalies, weak		Good	Excellent to good	Excellent
Alkalies, strong		Poor	Excellent to good	Good
Alcohols			Excellent to good	Good below 80°C
Ketones		Dissolves	Excellent to good	Good below 80°C
Esters		Dissolves	Excellent to good	Good below 80°C
Hydrocarbons, aliphatic		Good	Good to fair	Good below 80°C
Hydrocarbons, aromatic		Softens	Good to fair	Good below 80°C
Oils: vegetable, animal, mineral		Good	Good	
Miscellaneous Properties				
Clarity		Excellent	Transparent	Transparent
Color		Colorless	Colorless to sl. yellow	Colorless to sl. yellow
Refractive index, n_D		1.48–1.50	1.49	
Application ASTM specifications and test methods		D257, D150, D638, D792, D648, D696, D785, D256, D543, D542	D257, D150, D412, D256, D648, D543, D638, D785, D542	D257, D150, D412, D256, D648, D543, D638, D785, D542

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.	Cs, P, R, S	F, Fb, Mf, P, R, S	F, Fb, Mf, P, R, S
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.	Cs, E, F, Lq, MB, MC, MI	Cl, E, F, MB, MC, MI	Cl, E, F, MB, MC, MI

To convert psi to N/m^2, multiply by 6,895. For specific heat in J/kg·K, multiply by 4,184.

Properties	Chemical Class / Resin Type / Subclass or Modification	Methylmethacrylate / Thermoplastic / Unmodified	Polypropylene / Thermoplastic / Unmodified	Polypropylene / Thermoplastic / Unmodified
Electrical Properties				
D.C. resistivity, ohm-cm		$>10^{16}$	$>10^{13}$–10^{17}	$>10^{18}$
Dielectric constant, 60 cps		2.5–2.65	2.6–3.4	2.
Dielectric constant, 10^6 cps		2.5–2.65	2.5–3.1	2.
Dissipation factor, 60 cps		0.0001–0.0003	0.0006–0.008	0.0002
Dissipation factor, 10^6 cps		0.0001–0.0004	0.007–0.01	0.0002
Mechanical Properties				
Modulus of elasticity, 10^3 psi		400–600	$>10^{16}$	33–65
Tensile strength, psi		5,000–10,000	9,000–12,000	2,000–4,500
Ultimate elongation, %		1.0–2.5	1.0–2.5	200–400
Yield stress, psi				1,600–2,000
Yield strain, %				50–75
Rockwell hardness		M 65–M 85	M 75–M 90	D 50–D 65
Notched Izod impact strength, ft lb/in.		0.25–0.60	0.3–0.6	2.5–4.0
Specific gravity		1.04–1.08	1.05–1.1	2.1–2.3
Thermal Properties				
Burning rate		Medium to slow	Slow	Self-extinguishing
Heat distortion, 264 psi, °C			91–104	60
Specific heat, cal/g		0.32–0.35	0.32–0.35	0.25
Linear thermal expansion coefficient, 10^{-5}, °C		6.0–8.0	3.6–3.8	10
Maximum continuous service temperature, °C		66–82	77–88	260
Chemical Resistance				
Mineral acids, weak		Excellent	Excellent	Excellent
Mineral acids, strong		Excellent	Good to excellent	Excellent
Oxidizing acids, concentrated		Poor	Poor	Excellent
Alkalies, weak		Excellent	Excellent	Excellent
Alkalies, strong		Excellent	Good to excellent	Excellent
Alcohols		Excellent	Good to excellent	Excellent
Ketones		Dissolves	Dissolves	Excellent
Esters		Poor	Dissolves	Excellent
Hydrocarbons, aliphatic		Poor	Good	Excellent
Hydrocarbons, aromatic		Dissolves	Fair to good	Excellent
Oils: vegetable, animal, mineral		Fair to poor	Good to excellent	Excellent
Miscellaneous Properties				
Clarity		Transparent	Transparent	Translucent
Color		Colorless	Colorless to amber	Colorless to gray
Refractive index, n_D		1.59–1.60	1.56–1.57	1.30–1.40
Application ASTM specifications and test methods		D257, D150, D638, D792, D648, D696, D785, D256, D543, D542	D257, D150, D638, D792, D648, D696, D785, D256, D543, D542	

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.	F, Fb, Mf, P, R, S	F, Mf, P, R, S	F, L, P, R, S
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.	E, F, MB, MC, MI	Cl, E, F, MB, MC, MI	E, F, MC, MI

Properties	Chemical Class	Polytrifluoro-chloroethylene	Polyvinylchloride and Vinylchloride Acetate	Polyvinylchloride and Vinylchloride Acetate
	Resin Type	Thermoplastic	Thermoplastic	Thermoplastic
	Subclass or Modification	Unmodified	Unmodified, Rigid	Plasticized, Non-Rigid
Electrical Properties				
D.C. resistivity, ohm-cm		10^{18}	10^{12}–10^{16}	10^{11}–10^{14}
Dielectric constant, 60 cps		2.2–2.8	3.2–4.0	5.0–9.0
Dielectric constant, 10^6 cps		2.3–2.5	3.0–4.0	3.0–4.0
Dissipation factor, 60 cps		0.001	0.01–0.02	0.03–0.05
Dissipation factor, 10^6 cps		0.005	0.006–0.02	0.06–0.1
Mechanical Properties				
Modulus of elasticity, 10^3 psi		150	200–600	
Tensile strength, psi		4,500–6,000	5,000–9,000	1,500–3,000
Ultimate elongation, %		250	2.0–40	200–400
Yield stress, psi		4,200		
Yield strain, %		10	1.0–5.0	
Rockwell hardness		J 75–J 95	R 110–R 120	
Notched Izod impact strength, ft lb/in.		2.5–4.0	0.4–2.0	
Specific gravity		2.1–2.3	1.36–1.4	1.15–1.35
Thermal Properties				
Burning rate		Self-extinguishing	Self-extinguishing	Slow to self-extinguishing
Heat distortion, 264 psi, ˚C			60–80	
Specific heat, cal/g		0.22	0.2–0.28	0.36–0.5
Linear thermal expansion coefficient, 10^{-5}, ˚C		7.0	5.0–18	7.0–25
Maximum continuous service temperature, ˚C		200	70–74	80–105
Chemical Resistance				
Mineral acids, weak		Excellent	Excellent	Fair to good
Mineral acids, strong		Excellent	Good to excellent	Fair to good
Oxidizing acids, concentrated		Excellent	Fair to good	Poor to fair
Alkalies, weak		Excellent	Excellent	Fair to good
Alkalies, strong		Excellent	Good	Fair to good
Alcohols		Excellent	Excellent	Fair
Ketones		Excellent	Poor	Poor
Esters		Excellent	Poor	Poor
Hydrocarbons, aliphatic		Excellent	Excellent	Poor
Hydrocarbons, aromatic		Excellent	Poor	Poor
Oils: vegetable, animal, mineral		Excellent	Excellent	Poor
Miscellaneous Properties				
Clarity		Transparent	Transparent	Transparent
Color		Colorless to pale	Colorless to amber	Colorless to amber
Refractive index, n_D		1.43	1.54	1.50–1.55
Application ASTM specifications and test methods		D1430, D257, D150, D256, D792, D648, D542, D638, D785, D696, D543	D708, D728, D257, D256, D792, D648, D542, D150, D638, D696, D543	D1432, D257, D150, D543, D542

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.	F, Mf, P, R, S	F, Fb, I, Lq, Mf, P, R, S	F, L, P, R, S
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.	Cs, E, F, I, MC, MI, S	Cl, Cs, E, F, I, MB, MC, MI, S	Cl, Cs, E, MB, MC, MI, S

To convert psi to N/m², multiply by 6,895. For specific heat in J/kg·K, multiply by 4,184.

Properties	Chemical Class	Epoxy	Melamine-Formaldehyde	Melamine-Formaldehyde
	Resin Type	Thermosetting	Thermosetting	Thermosetting
	Subclass or Modification	Unfilled	α-Cellulose Filled	Mineral-Filled (Electrical)
Electrical Properties				
D.C. resistivity, ohm-cm		10^{12}–10^{14}	10^{12}–10^{14}	10^{13}–10^{14}
Dielectric constant, 60 cps		3.5–5.0	7.9–9.4	10.2
Dielectric constant, 10^6 cps		3.4–4.4	7.2–8.4	6.1
Dissipation factor, 60 cps		0.001–0.005	0.03–0.08	0.10
Dissipation factor, 10^6 cps		0.03–0.05	0.03–0.043	0.051
Mechanical Properties				
Modulus of elasticity, 10^3 psi		>300	1,300	1,950
Tensile strength, psi		4,000–13,000	7,000–13,000	5,500–6,500
Ultimate elongation, %		2.0–6.0	0.6–0.9	
Yield stress, psi				
Yield strain, %				
Rockwell hardness		M 75–M 110	M 110–M 124	E 90
Notched Izod impact strength, ft lb/in.		0.2–1.0	0.24–0.35	0.3–0.4
Specific gravity		1.115	1.47–1.52	1.78
Thermal Properties				
Burning rate		Slow	Self-extinguishing	Self-extinguishing
Heat distortion, 264 psi, °C		Up to 120	204	130
Specific heat, cal/g		0.25–0.4	0.4	
Linear thermal expansion coefficient, 10^{-5}, °C		4.5–9.0	2.0–5.7	2.1–4.3
Maximum continuous service temperature, °C		80	99.0	149
Chemical Resistance				
Mineral acids, weak		Excellent	Good	Fair
Mineral acids, strong		Fair to good	Poor	Poor
Oxidizing acids, concentrated		Poor	Poor	Poor
Alkalies, weak		Excellent	Good	Fair
Alkalies, strong		Excellent	Poor	Poor
Alcohols		Excellent	Good	Good
Ketones		Poor	Good	Good
Esters			Good	Good
Hydrocarbons, aliphatic		Excellent	Good	Good
Hydrocarbons, aromatic		Excellent	Good	Good
Oils: vegetable, animal, mineral		Excellent	Good	Good
Miscellaneous Properties				
Clarity		Transparent	Transparent	Opaque
Color		Colorless	Colorless	Dark
Refractive index, n_D		1.58		
Application ASTM specifications and test methods		D257, D150, D651, D792, D648, D696, D785, D256, D5432	D704, D257, D150, D256, D792, D648, D638, D785, D543, D696	D704, D257, D150, D256, D792, D648, D638, D785, D543, D696

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.	Cs, Lq	P, R, S	P, R, S
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.	Cs, I, S	MC	MC

Properties	Chemical Class	Phenol-Formaldehyde	Phenol-Formaldehyde	Phenol-Formaldehyde
	Resin Type	Thermosetting	Thermosetting	Thermosetting
	Subclass or Modification	Cord Filled	Cellulose Filled	Unfilled Cast Phenolic, Mechanical and Chemical Grade
Electrical Properties				
D.C. resistivity, ohm-cm		10^{11}–10^{12}	10^{11}–10^{13}	1.0–7.0×10^{12}
Dielectric constant, 60 cps		7.0–10.0	5.0–9.0	6.5–7.5
Dielectric constant, 10^6 cps		5.0–6.0	4.0–7.0	4.0–5.5
Dissipation factor, 60 cps		0.1–0.3	0.0–0.3	0.10–0.15
Dissipation factor, 10^6 cps		0.04–0.09	0.03–0.07	0.04–0.05
Mechanical Properties				
Modulus of elasticity, 10^3 psi		900–1,300	800–1,200	4.0–5.0
Tensile strength, psi		6,000–9,000	6,500–8,500	6,000–9,000
Ultimate elongation, %		0.5–1.0	0.6–1.0	1.5–2.0
Yield stress, psi				
Yield strain, %				
Rockwell hardness			M 110–M 120	M 93–M 120
Notched Izod impact strength, ft lb/in.		4.0–8.0	0.24–0.34	0.25–0.4
Specific gravity		1.36–1.43	1.32–1.55	1.307–1.318
Thermal Properties				
Burning rate		Self-extinguishing	Self-extinguishing	Self-extinguishing
Heat distortion, 264 psi, ˚C		121–127	143–171	74–80
Specific heat, cal/g			0.35–0.40	
Linear thermal expansion coefficient, 10^{-5}, ˚C			3.0–4.5	6.0–8.0
Maximum continuous service temperature, ˚C		121	149–177	
Chemical Resistance				
Mineral acids, weak		Variable	Variable	Fair to good
Mineral acids, strong		Poor	Poor	Poor to good
Oxidizing acids, concentrated		Poor	Poor	Poor
Alkalies, weak		Variable	Variable	Poor to good
Alkalies, strong		Poor	Poor	Poor
Alcohols		Good	Good to excellent	Good to excellent
Ketones		Poor to fair	Fair	Fair
Esters		Fair to good	Fair to good	Fair to good
Hydrocarbons, aliphatic		Fair to good	Excellent	Good to excellent
Hydrocarbons, aromatic		Fair to good	Excellent	Good
Oils: vegetable, animal, mineral		Good	Excellent	Excellent
Miscellaneous Properties				
Clarity		Opaque	Opaque	Clear
Color				Colorless to amber
Refractive index, n_D				
Application ASTM specifications and test methods		D700, D257, D150, D785, D256, D792, D638, D651, D543, D648	D700, D257, D150, D785, D256, D792, D543, D638, D651, D648, D696	D257, D150, D638, D792, D648, D696, D785, D256, D543

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.	L, P, S	L, P, S	Cs, R, S
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.	MC	MC	Cs, F

To convert psi to N/m², multiply by 6,895. For specific heat in J/kg·K, multiply by 4,184.

Properties	Chemical Class	Polyester (Styrene-Alkyd)	Silicones	Urea Formaldehyde
	Resin Type	Thermosetting	Thermosetting	Thermosetting
	Subclass or Modification	Glassfiber Mat Reinforced	Mineral Filled	α-Cellulose Filled
Electrical Properties				
D.C. resistivity, ohm-cm		10^{11}	$>10^{12}$	0.5–5.0
Dielectric constant, 60 cps		4.0–5.5	3.5–3.6	7.7–9.5
Dielectric constant, 10^6 cps		4.0–5.5	3.4–3.6	6.7–8.0
Dissipation factor, 60 cps		001–0.04	0.004	0.036–0.043
Dissipation factor, 10^6 cps		0.01–0.06	0.005–0.007	0.025–0.035
Mechanical Properties				
Modulus of elasticity, 10^3 psi		500–1,500		1,300–1,400
Tensile strength, psi		30,000–50,000	3,000–4,000	5,500–13,000
Ultimate elongation, %		0.5–1.5		0.6
Yield stress, psi				
Yield strain, %				
Rockwell hardness		M 80–M 120	M 85–M 95	E 94–E 97
Notched Izod impact strength, ft lb/in.		7.0–30	0.25–0.35	0.24–0.40
Specific gravity		1.5–2.1	1.8–2.8	1.47–1.52
Thermal Properties				
Burning rate		Self-extinguishing	Self-extinguishing	Self-extinguishing
Heat distortion, 264 psi, °C		93–288	>260	130
Specific heat, cal/g		0.2–0.4	0.2–0.3	0.6
Linear thermal expansion coefficient, 10^{-5}, °C		1.8–3.0	2.0–4.0	2.2–3.6
Maximum continuous service temperature, °C		121–204	288	77
Chemical Resistance				
Mineral acids, weak		Good	Fair to good	Poor
Mineral acids, strong		Poor	Poor to good	Poor
Oxidizing acids, concentrated		Poor		Poor
Alkalies, weak		Good	Fair	Fair
Alkalies, strong		Poor	Poor	Poor
Alcohols		Good	Poor	Good
Ketones		Poor	Poor	Good
Esters		Good		Good
Hydrocarbons, aliphatic		Good	Fair to good	Good
Hydrocarbons, aromatic		Poor to fair	Poor	Good
Oils: vegetable, animal, mineral		Good	Good	
Miscellaneous Properties				
Clarity		Translucent	Opaque	Translucent
Color		Colorless	Pale to dark	Colorless
Refractive index, n_D				1.54–1.56
Application ASTM specifications and test methods		D257, D150, D638, D792, D648, D696, D785, D256, D543	D257, D150, D785, D648, D696, D543, D256, D792	D705, D257, D150, D256, D792, D648, D638, D785

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.	L, S	P	P, R, S
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.	I	MC	MC

Properties — Chemical Class	Acrylonitrile-Butadiene-Styrene (ABS)	Acetal	Alkyd Resins
Resin Type	Thermoplastic	Thermoplastic	Thermosetting
Subclass or Modification	High-Heat Resistant	Homopolymer	Synthetic-Fiber Filled
Electrical Properties			
D.C. resistivity, ohm-cm			
Dielectric constant, 60 cps	2.4–5.0		3.8–5.0
Dielectric constant, 10^6 cps	2.4–3.8	3.7	3.6–4.7
Dissipation factor, 60 cps	0.003–0.008		0.012–0.026
Dissipation factor, 10^6 cps	0.007–0.015	0.004	0.01–0.016
Mechanical Properties			
Modulus of elasticity, 10^3 psi			
Tensile strength, psi	7,000–8,000	10,000–12,000	4,500–6,500
Ultimate elongation, %	1.0–20	15–75	
Yield stress, psi	4,000–9,000		10,000–13,000
Yield strain, %			
Rockwell hardness	R 110–R 115	M 94, R 120	E 76
Notched Izod impact strength, ft lb/in.	2.0–4.0	1.4–2.3	0.50–4.5
Specific gravity	1.06–1.08	1.43	1.24–2.6
Thermal Properties			
Burning rate	Slow	Slow	Self-extinguishing
Heat distortion, 264 psi, °C	115–118		
Specific heat, cal/g	0.3–0.4	0.35	
Linear thermal expansion coefficient, 10^{-5}, °C	6.0–6.5	8.1	4.0–5.5
Maximum continuous service temperature, °C	88–110	84	149–220
Chemical Resistance			
Mineral acids, weak	Good	Fair	Good
Mineral acids, strong	Good	Poor	Fair
Oxidizing acids, concentrated	Poor	Poor	
Alkalies, weak	Good	Poor	Good
Alkalies, strong	Good	Poor	Fair
Alcohols	Good	Good	Fair to good
Ketones	Poor	Good	Fair to good
Esters	Poor	Good	Fair to good
Hydrocarbons, aliphatic	Fair	Good	Fair to good
Hydrocarbons, aromatic	Fair	Good	Fair to good
Oils: vegetable, animal, mineral	Good	Good	
Miscellaneous Properties			
Clarity	Translucent to opaque	Translucent to opaque	Opaque
Color	Colorless	Colorless	Colorless
Refractive index, n_D		1.48	
Application ASTM specifications and test methods	D638, D150, D792, D256, D758, D696, D651, D648, D543	D638, D150, D792, D256, D758, D696, D651, D648, D543	D638, D150, D792, D256, D758, D543, D651, D648

Properties of Commercial Plastics (continued)

Forms Available Cs—castings, F—film, Fb—fibers, I—impregnants, L—laminations, Lq—lacquers, Mf—monofilaments, P—powder, pellet, or granules, R—rods, tubes, or other extruded forms, S—sheets.	P, S, L, R	C, R	P
Fabrication Cl—calendering, Cs—casting, E—extrusion, F—hot forming or drawing, I—impregnation, MB—blow molding, MC—compression molding, MI—injection molding, S—spreading.	Cl, E, MB, MI	MI, E	Cs, MC, MI

References

"Handbook of Common Polymers," W.J. Roff, J.R. Scott, J. Pacitti, Butterworth & Co., Ltd. (London), 1971; The Chemical Rubber Co., U.S. distributor.

ASTM Standards, American Society for Testing and Materials, 1972, Part 26.

"Modern Plastics Encyclopedia," Vol. 44, No. 1A, McGraw-Hill, Inc., 1967.

From Bolz, R.E. and Tuve, G.L., Solids — Non-metals, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, pp. 137–147.

Rubbers and Elastomers

Elastomers cannot be classified in any brief and simple manner, nor are they well characterized by the usual mechanical tests. The terms *rubber* and *synthetic rubber* are loosely applied to a great variety of elastic materials, from pure gum natural rubber and pure synthetics to cured, compounded, filled, and even reinforced products.

ASTM designations (D418) by chemical polymer description are used in the following table; yet within each class the properties can vary widely, depending on the exact composition, heat treatment, service temperature, and application. Typical uses, such as rubber springs and cushioning, permit an almost unlimited number of combinations of design variables.

Mechanically, rubbers may be expected to lose strength rapidly with increase in temperature, to show a large hysteresis in stress-strain behavior, to exhibit marked creep and set, and to be greatly affected by rates of load application or frequency of repeated stress. "Heat build-up," i.e., increase in temperature in service, as well as deterioration from environment (sunlight, oils, ozone, etc.) will reduce the valuable properties of many rubbers, both natural and synthetic.

The following data apply to typical samples of commercial elastomers for common uses.

Key:

A — Acetone
B — Benzene
C — Carbon tetrachloride
D — Carbon disulfide
E — Phenol
F — Sulfur compounds
G — Glycerol or glycol
H — Hexane
I — Acids
J — Alkalies
K — Ketones
L — Alcohols
M — Ammonia
N — Turpentine
O — Coal derivatives; bitumens
P — Petroleum products
R — Aromatics
S — Salts
T — Heat of high temperature
U — Ultraviolet
V — Vegetable oils
W — Weathering
X — Oxidation
Y — Aging
Z — Ozone

Chemical Name	Polyisoprene	Butadiene	Styrene-Butadiene	Acrylonitrile Butadiene
Other Names	Natural (or Synthetic) Rubber NR (IR)	BR Cis 4	Buna S Styrene SBR, GR-S	Nitrile, Buna N Hycar NBR, GR-A
Chemical and Physical				
Specific gravity	0.93	1.0	1.0	1.0
Specific heat	0.40	0.45	0.40	0.47
Thermal conductivity				
W/cm·K	0.001 7	0.002 5	0.002 6	0.002 5
Btu/hr·ft·deg F	0.10	0.14	0.15	0.14
Service temperature, deg C				
min	–25	–40	–20	–20
max	90	90	75	110
Solvents, softeners	D,K,P,V	D,H,N,P	K,P,R,V	C,K,O.R
Resistant to	A,I,J,L	G,I,J,W,Y	G,I.L,S,X	G,I,K,L,P,S,T,V,W
Swelled by	D,P,V	A,P,V	P,V	A,E.N
Mechanical and Electrical				
Tensile strength				
kg/cm^2 (max)	300.	210.	210.	295.
kpsi (max)	4.3	3.0	3.0	4.2
Elongation at break, %	600.	700.	600.	600.
Vol. resistivity, ohm-cm	10^{15}	10^{15}	10^{14}	10^{10}
Dielectric strength				
kV/cm	235		235	185
V/mil	600.		600.	475.
Dielectric constant	3.0	2.3	2.8	3.0
Power factor (50–100 Hz)	0.003	0.005	0.005	0.007
Rebound	Good	Good	Fair	Good
Comparative Ratings — Resistance to				
Abrasion	Good	Excellent	Good	Excellent
Cold flow (set)	Excellent		Good	Good
Tearing	Good		Poor	Fair

Rubbers and Elastomers

Chemical Name	Polyisoprene	Butadiene	Styrene-Butadiene	Acrylonitrile Butadiene
Other Names	Natural (or Synthetic) Rubber NR (IR)	BR Cis 4	Buna S Styrene SBR, GR-S	Nitrile, Buna N Hycar NBR, GR-A
Air permeability	Fair	Good	Fair	Excellent
Oxidation	Fair	Fair	Fair	Fair
Flame	Poor		Poor	Poor

Chemical Name	Polychloroprene	Isobutylene-Isoprene	Polysulfide	Polymethane
Other Names	Neoprene[a], CR, GR-M	Butyl, IIR, GR-I	Thiokol[a], PS, GR-P	Adiprene[a], PU
Chemical and Physical				
Specific gravity	1.25	0.95	1.4	1.2
Specific heat	0.5	0.45	0.31	0.45
Thermal conductivity				
W/cm·K	0.002 1	0.001 3	0.003	0.001 3
Btu/hr·ft·deg F	0.12	0.075	0.17	0.075
Service temperature, deg C				
min	–20	–40	–15	–35
max	100	120	90	120
Solvents, softeners	A,B,C,D,I,N,R	D,P	C	
Resistant to	G,L,P,S,T,U,V,W,Y,Z	E,G,J,S,U,V,W,X,Y,Z	L,P,U,Z	P,V,X,Z
Swelled by	C,D,N,R	D.H.P	C,R	B,C,K,R
Mechanical and Electrical				
Tensile strength				
kg/cm^2 (max)	240.	175.	90.	350.
kpsi (max)	3,5	2.5	1.3	5.0
Elongation at break, %	800.	700.	500.	550.
Vol. resistivity, ohm-cm	10^{11}	10^{17}	10^{8}	10^{11}
Dielectric strength				
kV/cm	195	295	125	195
V/mil	500	750	325	500
Dielectric constant	7.	2.4	8.	7.
Power factor (50–100 Hz)	.04	0.004	0.02	0.04
Rebound	Good	Poor	Poor	
Comparative Ratings—Resistance to				
Abrasion	Excellent	Fair	Poor	Excellent
Cold flow (set)	Excellent	Fair	Poor	Poor
Tearing	Good	Good	Poor	Excellent
Air permeability	Good	Excellent	Good	Excellent
Oxidation	Good	Good	Good	Good
Flame	Excellent	Poor	Poor	Poor

[a] Proprietary.

From Bolz, R.E. and Tuve, G.L., Solids — Non-metals, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, pp. 156–157.

Electrical Properties of Various Kinds of Glass

Values are for room temperature. In general the volume resistivity is reduced at the higher temperatures, but the dissipation factor increases rapidly above 100–200°C.

Types of Glass	Volume Resistivity, ohm-cm	Dielectric Constant, 1 Mhz	Dissipation Factor, 1 Mhz
Fused silica	10^{12}	3.8	0.0002
96% silica (7900, 7910–11–12)†	10^{10}	3.8	0.0005
Soda lime			
General-purpose	10^{6}–10^{7}	7.0–7.6	0.004–0.011
Lamp bulb (0080)	10^{7}	7.2	0.009
Lead alkali silicate			
Electrical (0010)	10^{9}	6.6	0.0016
High lead (8870)	10^{12}	9.5	0.009
Alumino borosilicate			
(Kimble N51a)	10^{7}	5.6	0.010
Borosilicate			
Low expansion (7740)	10^{8}	4.6	0.0046
Low electrical loss (7070)	10^{11}	4.0	0.0006
Tungsten sealing (7050)	10^{9}	4.9	0.0033
Aluminosilicate (1710–20)	10^{11}	6.3	0.0037

† Numbers in parentheses indicate equivalent Corning glass code numbers.

From Bolz, R.E. and Tuve, G.L., Solids — Non-metals, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 166. Originally from "Electrical Insulating Materials," *Machine Design*, 39:161, Sept. 28, 1967.

Properties of the Chemical Elements

Name	Symbol	Atomic Number	International at. wt.[a]	Specific Gravity (or density)	Melting Point, °C	Boiling Point, °C	Specific Heat at 25°C	Thermal Conductivity, watt/cm°C
Actinium	Ac	89	(227)	(10.02)	1050.	3200.	—	—
Aluminum	Al	13	26.9815	2.70	660.	2441.	0.215	2.37
Americium	Am	95	(243)	11.7	994.	2607.	—	—
Antimony (Stibium)	Sb	51	121.75	6.69	630.	1750.	0.050	0.185
Argon	Ar	18	39.948	1.78 g/l	–189.	–186.	0.125	175×10^{-4}
Arsenic	As	33	74.9216	5.73 (gray)	815.[b]	613. (subl.)	0.079	—
Astatine	At	85	(210)	—	729.	2125.	—	—
Barium	Ba	56	137.34	3.5	725.	1630.	0.046	—
Berkelium	Bk	97	(247)	—	—	—	—	—
Beryllium	Be	4	9.0122	1.85	1285.	2475.	0.436	2.18
Bismuth	Bi	83	208.980	9.75	271.4	1560.	0.030	0.084
Boron	B	5	10.811	2.35	2300.	2550.	0.245	—
Bromine	Br	35	79.904	3.12 (liq.)	–7.2	56.8	0.11	0.45×10^{-4}
Cadmium	Cd	48	112.40	8.65	321.	767.	0.055	0.92
Calcium	Ca	20	40.08	1.55	840.	1485.	—	1.3
Californium	Cf	98	(251)	—	—	—	—	—
Carbon	C	6	12.01115					
Diamond				3.5	>3800.	4827.	0.124	1.5 (0°)
Graphite				2.1	>3500.	4200.	0.170	0.24
Cerium	Ce	58	140.12	6.77	798.	3257.	0.047	0.11
Cesium	Cs	55	132.905	1.87	28.6	678.	0.057	—
Chlorine	Cl	17	35.453	3.21 g/l	–101.	–34.6	0.114	0.86×10^{-4}
Chromium	Cr	24	51.996	7.2	1860.	2670.	0.110	0.91
Cobalt	Co	27	58.9332	8.9	1495.	2870.	0.10	0.69
Copper	Cu	29	63.546	8.96	1084.	2575.	0.092	3.98
Curium	Cm	96	(247)	—	—	—	—	—
Dysprosium	Dy	66	162.50	8.54	1409.	2335.	0.0414	0.10
Einsteinium	Es	99	(254)	—	—	—	—	—
Erbium	Er	68	167.26	9.05	1522.	2510.	0.04	0.096
Europium	Eu	63	151.96	5.25	822.	1597.	0.042	—
Fermium	Fm	100	(257)	—		—	—	—
Fluorine	F	9	18.9984	1.11 (liq.)	–219.6	–188.	0.197	2.63×10^{-4}
Francium	Fr	87	(223)	—	27.	677.	—	—
Gadolinium	Gd	64	157.25	7.90	1311.	3233.	0.055	0.088
Gallium	Ga	31	69.72	5.91	29.8	2300.	0.089	0.29–0.38
Germanium	Ge	32	72.59	5.32	937.	2380.	0.077	0.59
Gold (Aurum)	Au	79	196.967	19.32	1063.	2857.	0.031	3.15
Hafnium	Hf	72	178.49	13.29	2220.	4700.	0.035	0.220
Helium	He	2	4.0026	0.177 g/l	—	–269.	1.24	14.8×10^{-4}
Holmium	Ho	67	164.930	8.78	1470.	2720.	0.039	—
Hydrogen	H	1	1.00797	0.0899 g/l	–259.	–253.	3.41	18.4×10^{-4}
Indium	In	49	114.82	7.31	156.	2050.	0.056	0.24
Iodine	I	53	126.9044	4.93	113.5	184.4	0.102	43.5×10^{-4}
Iridium	Ir	77	192.2	22.42	2450.	4390.	0.031	1.47
Iron (Ferrum)	Fe	26	55.847	7.87	1536.	2870.	0.108	0.803
Krypton	Kr	36	83.80	3.73 g/l	–157.	–152.	0.059	0.94×10^{-4}
Lanthanum	La	57	138.91	6.17	920.	3454.	0.047	0.14
Lawrencium	Lr	103	(257)	—	—	—	—	—
Lead (Plumbum)	Pb	82	207.19	11.35	327.5	1750.	0.031	0.352
Lithium	Li	3	6.939	0.53	180.	1342.	0.84	0.71
Lutetium	Lu	71	174.97	9.84	1656.	3315.	0.037	—
Magnesium	Mg	12	24.312	1.74	650.	1090.	0.243	1.56
Manganese	Mn	25	54.930	7.21–7.44	1244.	2060.	0.114	—
Mendelevium	Md	101	(256)	—	—	—	—	—
Mercury (Hydragyrum)	Hg	80	200.59	13.546	–38.86	356.55	0.033	0.0839

Properties of the Chemical Elements (continued)

Name	Symbol	Atomic Number	International at. wt.[a]	Specific Gravity (or density)	Melting Point, °C	Boiling Point, °C	Specific Heat at 25°C	Thermal Conductivity, watt/cm°C
Molybdenum	Mo	42	95.94	10.22	2620.	4651.	0.060	1.38
Neodymium	Nd	60	144.24	7.00	1010.	3127.	0.049	0.13
Neon	Ne	10	20.183	0.90 g/l	–249.	–246.	0.246	4.77×10^{-4}
Neptunium	Np	93	(237)	18.0–20.45	640.	3902.	0.296	—
Nickel	Ni	28	58.71	8.90	1453.	2914.	0.106	0.905
Niobium (Columbium)	Nb	41	92.906	8.57	2467.	4740.	0.064	0.53
Nitrogen	N	7	14.0067	1.251 g/l	–210.	–196.	0.249	2.55×10^{-4}
Nobelium	No	102	(254)	—	—	—	—	—
Osmium	Os	76	190.2	22.57	3025.	4225.	0.031	0.61
Oxygen	O	8	15.9994	1.43 g/l	–218.4	–183.	0.220	2.61×10^{-4}
Palladium	Pd	46	106.4	12.02	1550.	2927.	0.058	0.71
Phosphorus, white	P	15	30.9738	1.82	44.1	280.	0.18	—
Platinum	Pt	78	195.09	21.45	1770.	3825.	0.032	0.73
Plutonium	Pu	94	(244)	19.84	640.	3230.	0.032	0.08
Polonium	Po	84	(209)	9.32	254.	962.	0.030	—
Potassium (Kalium)	K	19	39.102	0.86	63.3	760.	0.180	0.99
Praseodymium	Pr	59	140.907	6.77	931.	3212.	0.046	0.12
Promethium	Pm	61	(145)	—	1080.	2460.	0.044	—
Protactnium	Pa	91	(231)	(15.37)	—	—	0.029	—
Radium	Ra	88	(226)	—	700.	1700.	0.029	—
Radon	Rn	86	(222)	9.73 g/l	–71.	–62.	0.0224	—
Rhenium	Re	75	186.2	21.0	3180.	5650.	0.033	0.71
Rhodium	Rh	45	102.905	12.41	1965.	3700.	0.058	1.50
Rubidium	Rb	37	85.47	1.532	39.	700.	0.086	—
Ruthenium	Ru	44	101.07	12.4	2400.	4100.	0.057	—
Samarium	Sm	62	150.35	7.54	1072.	1778.	0.047	—
Scandium	Sc	21	44.956	2.99	1539.	2832.	0.135	—
Selenium	Se	34	78.96	4.8	217.	700.	0.077	0.005
Silicon	Si	14	28.086	2.33	1411.	3280.	0.17	0.835
Silver (Argentum)	Ag	47	107.868	10.50	961.	2212.	0.057	4.27
Sodium (Natrium)	Na	11	22.9898	0.97	97.83	884.	0.293	1.34
Strontium	Sr	38	87.62	2.55	770.	1375.	0.072	—
Sulfur	S	16	32.064	1.96–2.07	113.	445.	0.175	26.4×10^{-4}
Tantalum	Ta	73	180.948	16.6	2980.	5365.	0.034	0.575
Technetium	Tc	43	(97)	(11.50)	2172.	4877.	0.058	—
Tellurium	Te	52	127.60	6.24	450.	990.	0.05	0.059
Terbium	Tb	65	158.924	8.23	1360.	3041.	0.0435	—
Thallium	Tl	81	204.37	11.85	304.	1480.	0.031	0.39
Thorium	Th	90	232.038	11.7	1750.	4800.	0.03	0.41
Thulium	Tm	69	168.934	9.31	1545.	1727.	0.0385	—
Tin (Stannum)	Sn	50	118.69	7.31	232.	2600.	0.054	0.67
Titanium	Ti	22	47.90	4.54	1670.	3290.	0.125	0.22
Tungsten (Wolfram)	W	74	183.85	19.3	3400.	5550.	0.032	1.78
Uranium	U	92	238.03	18.8	1132.	4140.	0.028	0.25
Vanadium	V	23	50.942	6.1	1900.	3400.	0.116	0.60
Xenon	Xe	54	131.30	5.89 g/l	–112	–107.	0.038	5.2×10^{-4}
Ytterbium	Yb	70	173.04	6.97	824.	1193.	0.071	—
Yttrium	Y	39	88.905	4.46	1523.	3337.	0.0925	0.15
Zinc	Zn	30	65.37	7.	419.5	910.	0.093	1.21
Zirconium	Zr	40	91.22	6.53	1852.	4400.	0.067	0.227

[a] Value in parentheses is the mass number of the most stable isotope of the element.
[b] At 28 atm.

From Bolz, R.E. and Tuve, G.L., Basic chemical data, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, pp. 329–330.

Additional Properties of the Chemical Elements

Name	Atomic Number	Latent Heat of Fusion, cal/g	Coef. of Linear Thermal Expansion × 106, K^{-1} 100	300	500	Elasticity Modulus, psi × 10^{-6}	First Ionization Potential, eV	Thermal Neutron Absorption Cross Section, Barns[a]
Actinium (227)	89	11	—	—	—	—	6.9	510.
Aluminum	13	95	12.5	24	27	10.0	5.984	0.24
American (243)	95	10	—	—	—	—	—	—
Antimony	51	38.5	9	9.5	10.5	11.3	8.639	5.7
Argon	18	6.7	—	—	—	—	15.755	0.66
Arsenic	33	88.5	—	4.7	—	—	9.81	4.3
Astatine	85	—	—	—	—	—	9.5	—
Barium	56	13.4	—	16	24	—	5.21	1.2
Berkelium	97	—	—	—	—	—	—	—
Beryllium	4	324	—	12	15	40–44	9.32	0.01
Bismuth	83	12.4	12	13	13.5	4.6	7.287	0.034
Boron	5	400	—	2	—	64	8.296	755
Bromine	35	16.2	—	—	—	—	11.84	6.7
Cadmium	48	13.2	26	30	38	8	8.991	2450.
Calcium	20	52	17.5	23	26	3.2–3.8	6.111	0.44
Californium (251)	98	—	—	—	—	—	—	—
Carbon (Graphite)	6	—	—	—	—	0.7	11.256	0.004
Cerium	58	9	—	8	—	4.4	5.6	0.73
Cesium	55	3.8	—	97	—	—	3.893	30.0
Chlorine	17	2.16	—	—	—	—	13.01	34.
Chromium	24	79	3.5	6	9.5	36	6.764	3.1
Cobalt	27	66	—	12	13	30	7.86	38.
Columbium See Niobium								
Copper	29	49	10.5	16.5	18	17	7.724	3.8
Curium (247)	96	—	—	—	—	—	—	—
Dysprosium	66	26.4	—	9.0	—	9.2	6.8	950.
Einsteinium (254)	99	—	—	—	—	—	—	—
Erbium	68	24.6	—	9.0	—	10.6	6.08	170.
Europium	63	16.9	—	26	—	2.1	5.67	4300.
Fermium	—	—	—	—	—	—	—	—
Fluorine	9	10.1	—	—	—	—	17 418	0.01
Francium	87	—	—	—	—	—	4	—
Gadolinium	64	16.4	—	4	—	8.1	6.16	46,000
Gallium	31	19.2	—	18	—	—	6	2.8
Germanium	32	114	2.5	5.6	6.5	—	7.88	2.45
Gold	79	15	11.5	14	15	10.8	9.22	98.8
Hafnium	72	34	—	6	—	20	7	105.
Helium	2	1.2	—	—	—	—	24.481	0.007
Holmium	67	—	—	—	—	9.7	—	65.
Hydrogen	1	15.0	—	—	—	—	13.595	0.33
Indium	49	6.8	25	33	—	—	5.785	191.
Iodine	53	15	—	93	—	—	10.454	7.0
Iridium	77	33	4	6.5	7.5	75	9	425.
Iron	26	65	6	12	14.5	28.5	7.87	2.6
Krypton	36	4.7	—	—	—	—	13.996	31.
Lanthanum	57	10	—	5	6.5	5.5	5.61	8.9
Lawrencium	103	—	—	—	—	—	—	—

Additional Properties of the Chemical Elements (continued)

Name	Atomic Number	Latent Heat of Fusion, cal/g	Coef. of Linear Thermal Expansion × 106, K^{-1} 100	300	500	Elasticity Modulus, psi × 10^{-6}	First Ionization Potential, eV	Thermal Neutron Absorption Cross Section, Barns[a]
Lead	82	5.5	25	29	32	2.0	7.415	0.18
Lithium	3	103	23	50	—	—	5.39	71.
Lutetium	71	26.4	—	—	—	12.2	—	112.
Magnesium	12	88.0	15	25	29	6.4	7.644	0.07
Manganese	25	64	11.5	23	28	23	7.432	13.3
Mendelevium	101	—	—	—	—	—	—	—
Mercury	80	2.7	—	—	—	—	10.43	375.
Molybdenum	42	69	3	5	5.5	40	7.10	2.7
Neodymium	60	13	—	7	7.5	5.5	5.51	46.
Neon	10	4.0	—	—	—	—	21.559	<2.8
Neptunium (237)	93	9.7	—	—	—	—	—	(170)
Nickel	28	71	6.5	13	15.5	31	7.633	4.6
Niobium	41	68	5	7	7.5	15	6.88	1.15
Nitrogen	7	6.2	—	—	—	—	14.53	1.9
Nobelium	102	—	—	—	—	—	—	—
Osmium	76	34	—	5	5.5	80	8.5	15.3
Oxygen	8	3.3	—	—	—	—	13.614	<0.000 2
Palladium	46	38	8.5	12	13	17	8.33	8.
Phosphorus	15	4.8	—	125	—	—	10.484	0.2
Platinum	78	24	6.8	8.9	9.5	21.3	9.0	8.8
Plutonium (244)	94	3	—	54	—	14	5.1	—
Polonium	84	11	—	—	—	—	8.43	—
Potassium	19	14.5	—	83	—	—	4.339	2.1
Praseodymium	59	17	—	5.	5.3	4.7	5.46	11.3
Promethium	61	—	—	—	—	6.1	—	—
Protactinium (231)	91	17	—	—	—	—	—	(200)
Radium (226)	88	10	—	—	—	—	5.277	(20)
Rodon (222)	86	3.1	—	—	—	—	10.746	(0.7)
Rhenium	75	42	—	7	—	66.7	7.87	85.
Rhodium	45	50	5.0	8.3	9.3	42	7.46	150.
Rubidium	37	6.3	—	90	—	—	4.176	0.7
Ruthenium	44	60	—	9	—	60	7.364	2.6
Samarium	62	24.7	—	—	—	4.9	5.6	5600.
Scandium	21	87	—	—	—	11.5	6.54	24.
Selenium	34	16	—	35	—	8.4	9.75	12.3
Silicon	14	430	—	2.5	3.5	16	8.149	0.160
Silver	47	26.5	14.3	19.0	20.6	10.5	7.574	63.
Sodium	11	27	45.7	70.0	—	—	5.138	.53
Strontium	38	25	—	—	—	—	5.692	1.21
Sulfur	16	9.2	42	63	—	—	10.357	0.52
Tantalum	73	41	5.2	6.6	6.9	27	7.88	21.
Technetium	43	56.7	—	—	—	—	7.28	22.
Tellurium	52	33	—	17	—	17	9.01	4.7
Terbium	65	23.6	—	7.0	—	8.3	5.98	46.
Thallium	81	5.0	24	29	32	—	6.106	3.4
Thorium	90	17	8.7	11.4	12.5	8.5	6.95	7.5
Thulium	69	26.0	—	—	—	11.0	5.81	127.
Tin	50	14.1	15.5	21	27.5	6	7.342	0.63

Additional Properties of the Chemical Elements (continued)

Name	Atomic Number	Latent Heat of Fusion, cal/g	Coef. of Linear Thermal Expansion × 106, K^{-1}			Elasticity Modulus, psi × 10^{-6}	First Ionization Potential, eV	Thermal Neutron Absorption Cross Section, Barns[a]
			100	300	500			
Titanium	22	100	4.4	8.6	9.8	16	6.82	5.8
Tungsten	74	46	2.7	4.4	4.6	50	7.98	19.
Uranium	92	12	10.6	13.5	17	24	6.08	7.7
Vanadium	23	98	4	8	—	19	6.74	5.
Xenon	54	4.2	—	—	—	—	12.127	35.
Ytterbium	70	12.7	—	25	26.3	2.6	6.2	37.
Yttrium	39	45	—	—	—	9.4	6.38	1.3
Zinc	30	27	23	30	32	12	9.391	1.10
Zirconium	40	54	3.9	5.5	6.2	13.7	6.84	0.18

[a] Values in parentheses apply only to that isotope for which the mass number is given following the name of the element. All other values of neutron cross section apply to the naturally occurring mixture of isotopes.

From Bolz, R.E. and Tuve, G.L., Basic chemical data, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, pp. 331–332.

Available Stable Isotopes of the Elements

Element and Mass No.	Natural Abundance, Percent
Hydrogen	
1	99.985
2	0.015
Helium	
3	0.00013
4	~100.0
Lithium	
6	7.42
7	92.58
Beryllium	
9	100.0
Boron	
10	19.78
11	80.22
Carbon	
12	98.99
13	1.11
Nitrogen	
14	99.63
15	0.37
Oxygen	
16	99.76
17	0.04
18	0.20
Fluorine	
19	100.0
Neon	
20	90.92
21	0.26
22	8.82
Sodium	
23	100.0
Magnesium	
24	78.70
25	10.13
26	11.17
Aluminum	
27	100.0
Silicon	
28	92.21
29	4.70
30	3.09
Phosphorus	
31	100.0
Sulfur	
32	95.0
33	0.76
34	4.22
36	0.014
Chlorine	
35	75.53
37	24.47
Argon	
36	0.34
38	0.06
40	99.60
Potassium	
39	93.1
40[a]	0.01
41	6.9
Calcium	
40	96.97
42	0.64
43	0.14
44	2.06
46	0.003
48	0.18
Scandium	
45	100.0
Titanium	
46	7.93
47	7.28
48	73.94
49	5.51
50	5.34
Vanadium	
50[b]	0.24
51	99.76
Chromium	
50	4.31
52	83.76
53	9.55
54	2.38
Manganese	
55	100.0
Iron	
54	5.82
56	91.66
57	2.19
58	0.33
Cobalt	
59	100.0
Nickel	
58	67.84
60	26.33
61	1.19
62	3.66
64	1.08
Copper	
63	69.09
65	30.91
Zinc	
64	48.89
66	27.81
67	4.11
68	18.57
70	0.62
Gallium	
69	60.4
71	39.6
Germanium	
70	20.52
72	27.43
73	7.76
74	36.54
76	7.76
Arsenic	
75	100.0
Selenium	
74	0.87
76	9.02
77	7.58
78	23.52
80	49.82
82	9.19
Bromine	
79	50.54
81	49.46
Krypton	
78	0.35
80	2.27
82	11.56
83	11.55
84	56.90
86	17.37
Rubidium	
85	72.15
87	27.85

Available Stable Isotopes of the Elements (continued)

Element and Mass No.	Natural Abundance, Percent	Element and Mass No.	Natural Abundance, Percent	Element and Mass No.	Natural Abundance, Percent
Strontium		Cadmium (cont.)		Barium (cont.)	
84	0.56	113	12.26	136	7.81
86	9.86	114	28.86	137	11.30
87	7.02	116	7.58	138	71.66
88	82.56				
		Indium		Lanthanum	
Yttrium		113	4.28	138	0.09
89	100.0	115[c]	95.72	139	99.91
Zirconium		Tin		Cerium	
90	51.46	112	0.96	136	0.193
91	11.23	114	0.66	138	0.250
92	17.11	115	0.35	140	88.48
94	17.40	116	14.30	142[d]	11.07
96	2.80	117	7.61		
		118	24.03	Praseodymium	
Niobium		119	8.58	141	100.0
93	100.0	120	32.85		
		122	4.72	Neodymium	
Molybdenum		124	5.94	142	27.11
92	15.84			143	12.17
94	9.04	Antimony		144	23.85
95	15.72	121	57.25	145	8.30
96	16.53	123	42.75	146	17.22
97	9.46			148	5.73
98	23.78	Tellurium		150	5.62
100	9.63	120	0.09	Samarium	
		122	2.46	144	3.09
Ruthenium		123	0.87	147[e]	14.97
96	5.51	124	4.61	148[f]	11.24
98	1.87	125	6.99	149[g]	13.83
99	12.72	126	18.71	150	7.44
100	12.62	128	31.79	152	26.72
101	17.07	130	34.48	154	22.71
102	31.61				
104	18.60	Iodine		Europium	
		127	100.0	151	47.82
Rhodium				153	52.18
103	100.0	Xenon			
		124	0.096	Gadolinium	
Palladium		126	0.090	152[h]	0.20
102	0.96	128	1.92	154	2.15
104	10.97	129	26.44	155	14.73
105	22.23	130	4.08	156	20.47
106	27.33	131	21.18	157	15.68
108	26.71	132	26.89	158	24.87
110	11.81	134	10.44	160	21.90
Silver		136	8.87		
107	51.82			Terbium	
109	48.18	Cesium		159	100.0
		133	100.0		
Cadmium				Dysprosium	
106	1.22	Barium		156[i]	0.052
108	0.88	130	0.101	158	0.090
110	12.39	132	0.097	160	2.29
111	12.75	134	2.42	161	18.88
112	24.07	135	6.59	162	25.53

Available Stable Isotopes of the Elements (continued)

Element and Mass No.	Natural Abundance, Percent	Element and Mass No.	Natural Abundance, Percent	Element and Mass No.	Natural Abundance, Percent
Dysprosium (cont.)		Hafnium (cont.)		Platinum (cont.)	
163	24.97	179	13.75	195	33.8
164	28.18	180	35.24	196	25.3
				198	7.2
Holmium					
165	100.0	Tantalum		Gold	
		180	0.012	197	100.0
		181	99.988		
Erbium				Mercury	
162	0.136			196	0.146
164	1.56	Tungsten		198	10.02
166	33.41	180	0.14	199	16.84
167	22.94	182	26.41	200	23.13
168	27.07	183	14.40	201	13.22
170	14.88	184	30.64	202	29.80
		186	28.41	204	6.85
Thulium		Rhenium			
169	100.0	185	37.07	Thallium	
		187[l]	62.93	203	29.50
Ytterbium				205	70.50
168	0.135	Osmium			
170	3.03	184	0.018	Lead	
171	14.31	186	1.59	204	1.48
172	21.82	187	1.64	206	23.6
173	16.13	188	13.3	207	22.6
174	31.84	189	16.1	208	52.3
176	12.73	190	26.4		
		192	41.0	Bismuth	
Lutetium				209	100.0
175	97.40	Iridium			
176[j]	2.60	191	37.3	Thorium	
		193	62.7	232[n]†	100.0
Hafnium					
174[k]	0.18	Platinum		Uranium	
176	5.20	190[m]	0.013	234[o]†	0.0006
177	18.50	192	0.78	235[p]†	0.72
178	27.14	194	32.9	238[q]†	99.27

[a] Half-life = 1.3×10^9y.
[b] Half-life > 10^{15}y.
[c] Half-life = 5×10^{14}y.
[d] Half-life = 5×10^{15}y.
[e] Half-life = 1.06×10^{11}y.
[f] Half-life = 1.2×10^{13}y.
[g] Half-life = 4×10^{14}y.
[h] Half-life = 1.1×10^{14}y.
[i] Half-life = 2×10^{14}y.
[j] Half-life = 2.2×10^{10}y.
[k] Half-life = 4.3×10^{15}y.
[l] Half-life = 4×10^{10}y.
[m] Half-life = 6×10^{11}y.
[n] Half-life = 1.4×10^{10}y.
[o] Half-life = 2.5×10^5y.
[p] Half-life = 7.1×10^8y.
[q] Half-life = 4.5×10^9y.
† Naturally occurring.

Reference

CRC Handbook of Radioactive Nuclides, Y. Wang, Ed., The Chemical Rubber Co., 1969, pp. 25–63.

From Bolz, R.E. and Tuve, G.L., Basic chemical data, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, pp. 334–336.

Energy Absorption Mass Attenuation Coefficient In cm²/g

Only a fraction of the events represented by the total attenuation cross section actually removes the gamma-ray. In particular, Compton scattering can cause a change in the direction and the energy of a photon without absorbing it. The energy absorption mass attenuation coefficient (μ_e/ρ) is a measure of the fraction of the gamma-ray energy that is converted from radiant energy into heat. The product of these coefficients and of the density of the material gives the energy absorption cross section.

	Gamma-Ray Energy, Mev						
Material	0.1	0.2	0.5	1.0	2	5	10.0
H	.0411	.0531	.0591	.0557	.0467	.0318	.0255
Be	.0183	.0237	.0264	.0248	.0210	.0151	.0118
C	.0215	.0267	.0297	.0280	.0237	.0177	.0145
N	.0224	.0267	.0297	.0280	.0236	.0180	.0151
O	.0233	.0271	.0297	.0280	.0238	.0183	.0157
Na	.0289	.0266	.0284	.0268	.0229	.0185	.0168
Mg	.0335	.0278	.0293	.0276	.0237	.0194	.0180
Al	.0373	.0275	.0286	.0270	.0232	.0192	.0182
Si	.0435	.0286	.0290	.0274	.0236	.0198	.0189
P	.0501	.0292	.0290	.0271	.0234	.0200	.0195
S	.0601	.0310	.0300	.0279	.0242	.0209	.0206
A	.0729	.0302	.0272	.0252	.0220	.0195	.0197
K	.0909	.0340	.0295	.0272	.0237	.0214	.0219
Ca	.111	.0367	.0304	.0279	.0244	.0222	.0231
Fe	.225	.0489	.0294	.0261	.0231	.0227	.0250
Cu	.310	.0594	.0296	.0260	.0229	.0231	.0261
Mo	.922	.141	.0348	.0263	.0233	.0262	.0316
Sn	1.469	.222	.0403	.0268	.0233	.0276	.0339
I	1.726	.260	.0433	.0274	.0236	.0283	.0353
W	4.112	.631	.0786	.0353	.0271	.0335	.0426
Pt	4.645	.719	.0892	.0375	.0280	.0343	.0438
Tl	5.057	.791	.0972	.0393	.0288	.0349	.0446
Pb	5.193	.821	.0994	.0402	.0293	.0352	.0450
U	9.63	1.096	.132	.0482	.0324	.0374	.0474
Air	.0233	.0268	.0297	.0280	.0238	.0181	.0153
NaI	1.466	.224	.0410	.0273	.0235	.0268	.0325
H_2O	.0253	.0300	.0330	.0311	.0264	.0198	.0165
Concrete	.0416	.0289	.0296	.0278	.0239	.0194	.0177
Tissue	.0271	.0293	.0320	.0300	.0256	.0192	.0160

From Bolz, R.E. and Tuve, G.L., Reactors and materials, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 466. Originally from *Reactor Physics Constants*, 2nd ed., Argonne National Laboratory, ANL-5800, U.S. Atomic Energy Commission, July 1963.

Gamma-Ray Absorption Cross Section In cm^{-1}

Material	Density, g/cm^3	Gamma-Ray Energy, Mev						
		0.1	0.2	0.5	1.0	2	5	10.0
Be	1.85	.0339	.0438	.0488	.0459	.0389	.0279	.0218
C	2.25	.0484	.0601	.0668	.0630	.0533	.0398	.0326
Na	.9712	.0281	.0258	.0276	.0260	.0222	.0180	.0163
Mg	1.741	.0583	.0484	.0510	.0481	.0413	.0338	.0313
Al	2.70	.1007	.0743	.0772	.0729	.0626	.0518	.0491
Si	2.42	.1053	.0692	.0702	.0663	.0571	.0479	.0457
P	1.83	.0917	.0534	.0531	.0496	.0428	.0366	.0357
S	2.07	.1244	.0642	.0621	.0578	.0501	.0433	.0426
K	0.87	.0791	.0296	.0257	.0237	.0206	.0186	.0191
Ca	1.55	.172	.0569	.0471	.0432	.0378	.0344	.0358
Fe	7.86	1.769	.3844	.2311	.2051	.1816	.1784	.1965
Cu	8.933	2.769	.5306	.2644	.2323	.2046	.2064	.2332
Mo	9.01	8.307	1.270	.3155	.2370	.2099	.2361	.2847
Sn	7.298	10.721	1.620	.2941	.1956	.1700	.2014	.2474
I	4.94	8.704	1.284	.2139	.1354	.1166	.1398	.1744
W	19.3	79.362	12.178	1.517	.6813	.5320	.6466	.8222
Pt	21.37	99.264	15.365	1.906	.8014	.5984	.7330	.9360
Tl	11.86	59.976	9.381	1.153	.4661	.3416	.4139	.5290
Pb	11.34	58.889	9.310	1.127	.4559	.3323	.3992	.5103
U	18.7	180.08	20.495	2.468	.9013	.6059	.6994	.8864
NaI	3.667	5.376	.8214	.1503	.1001	.0862	.0983	.1192
H_2O	1.00	.0253	.0300	.0330	.0311	.0264	.0198	.0165
Concrete	2.35	.0978	.0679	.0697	.0653	.0562	.0456	.0416

From Bolz, R.E. and Tuve, G.L., Reactors and materials, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 467. Originally from *Reactor Physics Constants*, 2nd ed., Argonne National Laboratory, ANL-5800, U.S. Atomic Energy Commission, July 1963.

Removal Cross Sections for Various Materials

The removal cross section is a measure of the ability of a material to remove fast neutrons for shielding attenuation. It is most often applied to a wall of solid material between the fission source and a layer of water or hydrogenous material. The solid wall reduces the neutron energy to such an extent that it will be thermalized and captued in the water.

Symbols: σ_R = microscopic removal cross section, barns/atom
Σ_R = macroscopic removal cross section per cm

Material	σ_R, Barn	N_0 at 20°C, atom/cm^3	Σ_R, cm^{-1}	Material	σ_R, Barn	N_0 at 20°C, atom/cm^3	Σ_R, cm^{-1}
Hydrogen	1.00 ± 0.05	—	—	Lead	3.53 ± 0.30	0.0330	0.116
Deuterium	0.92 ± 0.10[a]	—	—	Bismuth	3.49 ± 0.35	0.0282	0.098
Lithium	1.01 ± 0.04	0.0460 × 10^{24}	0.146	Uranium	3.6 ± 0.4	0.0473	0.17
Beryllium	1.07 ± 0.06	0.120	0.128	Boric Acid (B_2O_3)	4.30 ± 0.41	—	—
Boron	0.97 ± 0.10	0.139	0.135	Boron carbide (B_4C)	5.1 ± 0.4	—	—
Carbon (graphite)	0.72 ± 0.05	0.113	0.081	Fluorothene (C_2F_3Cl)	6.66 ± 0.8	—	—
Oxygen	0.92 ± 0.05	—	—	Heavy water (D_2O)	2.76 ± 0.11	—	—
Fluorine	1.29 ± 0.06	—	—	Lithium fluoride (LiF)	2.43 ± 0.34	—	—
Aluminum	1.31 ± 0.05	0.0603	0.079	Oil (CH_2)	2.84 ± 0.11	—	—
Chlorine	1.2 ± 0.8	—	—	Paraffin ($C_{30}H_{62}$)	80.5 ± 5.2	—	—
Iron	1.98 ± 0.08	0.0848	0.168	Perfluoroheptane (C_7F_{16})	26.3 ± 0.8	—	—
Nickel	1.89 ± 0.10	0.0913	0.173				
Copper	2.04 ± 0.11	0.,0846	0.173				
Zirconium	2.36 ± 0.12	0.0423	0.10				
Tungsten	3.13 ± 0.25	0.0631	0.198				

[a] Calculated: $\sigma_R(D_2O)$ = 2.76 b.

Reference

"Effective Neutron Removal Cross Sections for Shielding," G.T. Chapman and C.L. Storrs, AECD-3978 (ORNL-1843), September 19, 1955.

From Bolz, R.E. and Tuve, G.L., Reactors and materials, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 467. Originally from *Reactor Physics Constants*, 2nd ed., Argonne National Laboratory, ANL-5800, U.S. Atomic Energy Commission, July 1963.

Diffusion of Gases and Vapors into Air

Values of Diffusion Constant and Schmidt Number at 1 atm Pressure

Substance	Diffusion Constant, D, sq ft/hr 0°C	25°C	Diffusion Constant, D, sq cm/sec 0°C	25°C	$(\mu/\rho D)^{\dagger}$ 0°C	25°C
H_2	2.37	2.76	0.611	0.712	0.217	0.216
NH_3	0.766	0.886	0.198	0.229	0.669	0.673
N_2	0.691		0.178		0.744	
O_2	0.689	0.80	0.178	0.206	0.744	0.748
CO_2	0.550	0.635	0.142	0.164	0.933	0.940
CS_2	0.36	0.414	0.094	0.107	1.41	1.44
Methyl alcohol	0.513	0.615	0.132	0.159	1.00	0.969
Formic acid	0.509	0.615	0.131	0.159	1.01	0.969
Acetic acid	0.411	0.515	0.106	0.133	1.25	1.16
Ethyl alcohol	0.394	0.461	0.102	0.119	1.30	1.29
Chloroform	0.352		0.091		1.46	
Diethylamine	0.342	0.406	0.0884	0.105	1.50	1.47
n-Propyl alcohol	0.329	0.387	0.085	0.100	1.56	1.54
Propionic acid	0.328	0.383	0.0846	0.099	1.57	1.56
Methyl acetate	0.325	0.387	0.0840	0.100	1.58	1.54
Butylamine	0.318	0.391	0.0821	0.101	1.61	1.53
Ethyl ether	0.304	0.360	0.0786	0.093	1.69	1.66
Benzene	0.291	0.341	0.0751	0.088	1.76	1.75
Ethyl acetate	0.277	0.330	0.0715	0.085	1.85	1.81
Toluene	0.274	0.325	0.0709	0.084	1.87	1.83
n-Butyl alcohol	0.272	0.348	0.0703	0.090	1.88	1.71
i-Butyric acid	0.263	0.313	0.0679	0.081	1.95	1.90
Chlorobenzene		0.283		0.073		2.11
Aniline	0.236	0.279	0.0610	0.072	2.17	2.14
Xylene	0.228	0.275	0.059	0.071	2.25	2.17
Amyl alcohol	0.228	0.271	0.0589	0.070	2.25	2.20
n-Octane	0.195	0.232	0.0505	0.060	2.62	2.57
Naphthalene	0.199	0.20	0.0513	0.052	2.58	2.96

† Based on μ/ρ = 0.1325 sq cm/sec for air at 0°C and 0.1541 sq cm/sec for air at 25°C; applies only when the diffusing gas or vapor is very dilute.

From Bolz, R.E. and Tuve, G.L., Heat and mass transfer, in *CRC Handbook of Tables for Applied Engineering Science*, CRC Press, Boca Raton, FL, 1973, p. 546.

Speed of Sound in Water and Steam (m·s^{-1})

	Pressure (MPa)													
t (°C)	0.01	0.02	0.05	0.1	0.2	0.5	1	2	5	10	20	50	75	100
Sat. Liq.	1540.0	1553.8	1556.6	1545.5	1520.7	1462.0	1391.6	1290.6	1088.4	847.7	422.2			
Sat. Vap.	440.5	449.5	462.2	472.1	481.9	493.8	500.9	504.7	498.2	472.4	384.5			
0	1402.3	1402.3	1402.4	1402.4	1402.6	1403.1	1403.8	1405.4	1410.2	1418.2	1434.5	1485.9	1530.6	1575.5
10	1447.4	1447.4	1447.5	1447.6	1447.7	1448.2	1449.0	1450.6	1455.3	1463.3	1479.6	1530.0	1573.3	1616.8
20	1483.3	1483.3	1483.3	1483.4	1483.6	1484.0	1484.8	1486.4	1491.2	1499.2	1515.3	1564.9	1607.2	1649.6
25	1498.0	1498.0	1498.1	1498.2	1498.3	1498.8	1499.6	1501.2	1506.0	1514.0	1530.1	1579.5	1621.4	1663.4
30	1510.8	1510.9	1510.9	1511.0	1511.1	1511.6	1512.4	1514.0	1518.8	1526.8	1543.0	1592.3	1634.1	1675.8
40	1531.2	1531.2	1531.2	1531.3	1531.5	1531.9	1532.8	1534.4	1539.2	1547.4	1563.7	1613.3	1655.0	1696.4
50	443.7	1545.2	1545.2	1545.3	1545.5	1546.0	1546.8	1548.5	1553.5	1561.8	1578.4	1628.7	1670.8	1712.2
60	450.7	1553.7	1553.8	1553.9	1554.0	1554.5	1555.4	1557.1	1562.3	1570.8	1587.9	1639.3	1682.0	1723.7
70	457.5	456.7	1557.5	1557.6	1557.8	1558.3	1559.2	1561.0	1566.3	1575.2	1592.9	1645.6	1689.1	1731.3
80	464.1	463.4	1557.0	1557.1	1557.2	1557.8	1558.7	1560.6	1566.2	1575.4	1593.7	1648.1	1692.6	1735.4
90	470.5	470.0	468.3	1552.8	1553.0	1553.5	1554.5	1556.5	1562.3	1571.9	1591.0	1647.2	1692.8	1736.3
100	476.9	476.4	475.0	472.3	1545.3	1545.9	1546.9	1549.0	1555.1	1565.1	1585.0	1643.2	1690.1	1734.4
110	483.1	482.7	481.4	479.3	1534.6	1535.2	1536.3	1538.4	1544.8	1555.4	1576.2	1636.5	1684.8	1730.0
120	489.2	488.9	487.8	485.9	1521.0	1521.7	1522.8	1525.1	1531.8	1543.0	1564.7	1627.4	1677.1	1723.4
130	495.3	495.0	494.0	492.3	488.8	1505.6	1506.8	1509.2	1516.3	1528.0	1550.8	1616.0	1667.4	1714.7
140	501.2	500.9	500.1	498.6	495.5	1487.0	1488.3	1490.8	1498.4	1510.7	1534.7	1602.5	1655.6	1704.3
150	507.1	506.8	506.0	504.7	502.0	1466.0	1467.4	1470.1	1478.1	1491.2	1516.5	1587.2	1642.2	1692.1
160	512.8	512.6	511.9	510.7	508.3	500.2	1444.3	1447.2	1455.7	1469.6	1496.2	1570.1	1627.1	1678.5
170	518.5	518.3	517.7	516.6	514.4	507.3	1418.9	1422.0	1431.1	1445.8	1474.0	1551.4	1610.4	1663.6
180	524.1	523.9	523.4	522.4	520.4	514.1	501.0	1394.6	1404.3	1420.1	1450.0	1531.0	1592.4	1647.3
190	529.7	529.5	529.0	528.1	526.3	520.6	509.7	1365.0	1375.4	1392.2	1424.0	1509.1	1572.9	1629.8
200	535.1	535.0	534.5	533.7	532.0	526.8	517.3	1333.2	1344.3	1362.3	1396.2	1485.8	1552.2	1611.2
220	545.8	545.7	545.3	544.6	543.2	538.9	531.2	512.6	1275.4	1296.1	1334.8	1434.7	1506.9	1570.7
240	556.3	556.2	555.9	555.3	554.1	550.4	544.0	529.5	1197.1	1221.1	1265.7	1378.0	1457.1	1526.2
260	566.0	566.5	566.2	565.6	564.6	561.5	556.1	544.1	1107.7	1136.3	1188.5	1316.0	1402.9	1478.1
280	576.6	576.5	576.2	575.8	574.9	572.2	567.5	557.4	518.9	1038.9	1102.1	1249.0	1345.1	1426.9
300	586.4	586.3	586.1	585.7	584.9	582.6	578.5	569.9	538.8	922.8	1004.3	1177.3	1284.3	1373.4
320	596.0	595.9	595.7	595.4	594.7	592.6	589.1	581.7	555.8	491.7	890.3	1101.5	1221.3	1318.5
340	605.4	605.3	605.1	604.8	604.2	602.4	599.3	592.9	570.9	522.2	751.1	1021.7	1157.0	1263.0
360	614.6	614.5	614.4	614.1	613.6	612.0	609.2	603.6	584.8	545.5	542.7	936.0	1091.6	1207.4
380	623.7	623.6	623.5	623.2	622.8	621.3	618.9	613.9	597.6	565.0	461.3	846.8	1023.5	1150.7
400	632.6	632.5	632.4	632.2	631.8	630.5	628.3	623.9	609.6	582.0	507.3	755.1	955.9	1093.3
420	641.3	641.3	641.2	641.0	640.6	639.4	637.5	633.5	620.9	597.3	538.7	666.1	890.2	1037.2
440	649.9	649.9	649.8	649.6	649.2	648.2	646.5	642.9	631.7	611.3	563.4	593.6	828.7	983.7
460	658.4	658.3	658.2	658.1	657.8	656.8	655.3	652.1	642.1	624.2	584.1	556.7	774.3	934.4
480	666.7	666.6	666.6	666.4	666.1	665.3	663.9	661.0	652.1	636.4	602.3	554.8	730.1	890.4
500	674.9	674.8	674.8	674.6	674.4	673.6	672.3	669.8	661.8	647.9	618.6	568.9	698.6	852.7
520	682.9	682.9	682.8	682.7	682.5	681.8	680.7	678.3	671.2	658.8	633.5	588.1	680.3	821.9
540	690.9	690.9	690.8	690.7	690.5	689.9	688.8	686.7	680.3	669.3	647.2	607.7	673.0	798.0
560	698.7	698.7	698.6	698.6	698.4	697.8	696.9	694.9	689.2	679.4	660.1	626.2	674.1	781.0
580	706.4	706.4	706.4	706.3	706.1	705.6	704.8	703.0	697.8	689.1	672.2	643.4	679.5	770.0
600	714.1	714.1	714.0	713.9	713.8	713.3	712.5	711.0	706.3	698.5	683.7	659.2	687.4	766.5
620	721.6	721.6	721.5	721.5	721.3	720.9	720.2	718.8	714.6	707.7	694.7	673.9	697.2	762.8
640	729.0	729.0	729.0	728.9	728.8	728.4	727.8	726.5	722.8	716.6	705.2	687.7	707.9	764.7
660	736.4	736.3	736.3	736.3	736.1	735.8	735.2	734.1	730.7	725.3	715.3	700.7	718.9	770.5
680	743.6	743.6	743.6	743.5	743.4	743.1	742.6	741.6	738.6	733.7	725.0	713.1	730.0	777.3
700	750.8	750.7	750.7	750.7	750.6	750.3	749.9	749.0	746.3	742.0	734.5	725.0	741.0	784.1

Speed of Sound in Water and Steam (m·s^{-1}) (continued)

	Pressure (MPa)													
t (°C)	0.01	0.02	0.05	0.1	0.2	0.5	1	2	5	10	20	50	75	100
720	757.8	757.8	757.8	757.8	757.7	757.4	757.0	756.2	753.9	750.1	743.6	736.3	751.9	790.9
740	764.8	764.8	764.8	764.8	764.7	764.5	764.1	763.4	761.3	758.1	752.6	747.2	762.5	797.9
760	771.8	771.8	771.7	771.7	771.6	771.4	771.1	770.5	768.7	765.9	761.2	757.7	772.8	805.2
780	778.6	778.6	778.6	778.6	778.5	778.3	778.1	777.5	776.0	773.6	769.7	767.7	782.6	812.8
800	785.3	785.3	785.3	785.3	785.2	785.1	784.9	784.4	783.2	781.3	778.0	777.4	791.8	821.0

From ASME International Steam Tables for Industrial Use.

Dynamic Viscosity of Water and Steam (mPa·s)

	Pressure (MPa)													
t (°C)	0.01	0.02	0.05	0.1	0.2	0.5	1	2	5	10	20	50	75	100
Sat. Liq.	587.6	466.0	348.6	282.9	231.6	180.1	150.2	126.1	100.0	81.8	56.2			
Sat. Vap.	10.5	10.9	11.6	12.3	13.0	14.1	15.0	16.1	18.0	20.3	27.5			
0	1791.8	1791.7	1791.7	1791.5	1791.3	1790.5	1789.3	1786.8	1779.5	1767.9	1746.6	1696.5	1668.8	1652.0
10	1306.0	1306.0	1305.9	1305.9	1305.8	1305.4	1304.9	1303.8	1300.7	1295.7	1286.6	1266.4	1256.7	1252.7
20	1001.6	1001.6	1001.6	1001.6	1001.6	1001.4	1001.2	1000.8	999.6	997.7	994.4	988.4	987.2	989.3
25	890.1	890.1	890.1	890.1	890.1	890.0	889.9	889.6	889.0	888.0	886.4	884.5	885.9	889.7
30	797.4	797.4	797.4	797.3	797.3	797.3	797.3	797.2	796.9	796.6	796.2	797.2	800.4	805.4
40	653.0	653.0	653.0	653.0	653.0	653.0	653.1	653.1	653.4	653.9	655.0	659.7	665.0	671.4
50	10.6	546.8	546.8	546.9	546.9	546.9	547.0	547.2	547.7	548.6	550.6	557.2	563.5	570.6
60	10.9	466.4	466.4	466.4	466.4	466.5	466.6	466.8	467.5	468.6	471.0	478.6	485.4	492.6
70	11.3	11.3	403.9	403.9	403.9	404.0	404.1	404.4	405.1	406.4	409.0	417.0	423.9	431.1
80	11.6	11.6	354.3	354.4	354.4	354.5	354.6	354.9	355.6	357.0	359.6	367.8	374.7	381.7
90	12.0	12.0	11.9	314.4	314.4	314.5	314.7	314.9	315.7	317.1	319.7	327.9	334.7	341.5
100	12.3	12.3	12.3	12.3	281.8	281.9	282.0	282.3	283.1	284.4	287.1	295.1	301.7	308.4
110	12.7	12.7	12.7	12.6	254.7	254.8	254.9	255.2	256.0	257.3	260.0	267.8	274.3	280.7
120	13.1	13.1	13.1	13.0	232.1	232.1	232.3	232.5	233.3	234.6	237.2	244.9	251.2	257.4
130	13.5	13.5	13.4	13.4	13.3	213.0	213.1	213.3	214.1	215.4	218.0	225.5	231.6	237.6
140	13.8	13.8	13.8	13.8	13.7	196.6	196.7	197.0	197.7	199.0	201.5	208.9	214.8	220.6
150	14.2	14.2	14.2	14.2	14.1	182.5	182.6	182.8	183.6	184.9	187.3	194.6	200.4	206.0
160	14.6	14.6	14.6	14.6	14.5	14.4	170.3	170.6	171.3	172.6	175.0	182.1	187.8	193.3
170	15.0	15.0	15.0	15.0	14.9	14.8	159.6	159.9	160.6	161.8	164.2	171.2	176.8	182.1
180	15.4	15.4	15.4	15.4	15.3	15.2	15.0	150.4	151.1	152.4	154.8	161.7	167.1	172.3
190	15.8	15.8	15.8	15.8	15.7	15.6	15.5	142.0	142.7	143.9	146.3	153.2	158.5	163.7
200	16.2	16.2	16.2	16.2	16.1	16.1	15.9	134.4	135.2	136.4	138.8	145.6	150.9	155.9
220	17.0	17.0	17.0	17.0	17.0	16.9	16.8	16.5	122.2	123.5	125.9	132.7	137.9	142.8
240	17.8	17.8	17.8	17.8	17.8	17.7	17.6	17.4	111.3	112.6	115.2	122.1	127.3	132.1
260	18.6	18.6	18.6	18.6	18.6	18.6	18.5	18.3	101.8	103.2	105.9	113.1	118.4	123.2
280	19.5	19.5	19.5	19.5	19.4	19.4	19.3	19.2	18.8	94.7	97.7	105.4	110.8	115.6
300	20.3	20.3	20.3	20.3	20.3	20.2	20.2	20.1	19.8	86.5	90.1	98.5	104.1	109.1
320	21.1	21.1	21.1	21.1	21.1	21.1	21.0	21.0	20.7	20.7	82.5	92.2	98.2	103.3
340	22.0	22.0	22.0	22.0	21.9	21.9	21.9	21.8	21.7	21.7	74.2	86.2	92.8	98.2
360	22.8	22.8	22.8	22.8	22.8	22.8	22.7	22.7	22.6	22.6	62.8	80.3	87.7	93.4
380	23.6	23.6	23.6	23.6	23.6	23.6	23.6	23.5	23.5	23.6	25.8	74.3	82.8	89.0
400	24.5	24.5	24.5	24.5	24.4	24.4	24.4	24.4	24.4	24.5	26.0	68.0	78.0	84.8

Dynamic Viscosity of Water and Steam (mPa·s) (continued)

	Pressure (MPa)													
t (˚C)	0.01	0.02	0.05	0.1	0.2	0.5	1	2	5	10	20	50	75	100
420	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.2	25.4	26.7	61.2	73.2	80.7
440	26.1	26.1	26.1	26.1	26.1	26.1	26.1	26.1	26.1	26.3	27.4	53.9	68.5	76.8
460	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	27.0	27.2	28.2	47.4	64.0	73.0
480	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8	28.0	29.0	43.0	59.6	69.4
500	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.6	28.7	28.9	29.8	40.5	55.8	66.1
520	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.5	29.8	30.7	39.3	52.6	63.0
540	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.2	30.4	30.6	31.5	38.8	50.2	60.3
560	31.0	31.0	31.0	31.0	31.0	31.0	31.0	31.1	31.2	31.4	32.3	38.7	48.5	58.0
580	31.8	31.8	31.8	31.8	31.8	31.8	31.8	31.9	32.0	32.3	33.1	38.8	47.3	56.2
600	32.6	32.6	32.6	32.6	32.6	32.6	32.6	32.7	32.8	33.1	33.9	39.1	46.6	54.7
620	33.4	33.4	33.4	33.4	33.4	33.4	33.4	33.5	33.6	33.9	34.7	39.5	46.1	53.6
640	34.2	34.2	34.2	34.2	34.2	34.2	34.2	34.3	34.4	34.7	35.5	40.0	46.0	52.7
660	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.1	35.2	35.5	36.3	40.5	45.9	52.2
680	35.8	35.8	35.8	35.8	35.8	35.8	35.8	35.9	36.0	36.3	37.1	41.1	46.1	51.8
700	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.8	37.1	37.8	41.6	46.3	51.6
720	37.3	37.3	37.3	37.3	37.3	37.3	37.4	37.4	37.6	37.8	38.6	42.2	46.6	51.5
740	38.1	38.1	38.1	38.1	38.1	38.1	38.1	38.2	38.3	38.6	39.4	42.9	46.9	51.5
760	38.9	38.9	38.9	38.9	38.9	38.9	38.9	38.9	39.1	39.4	40.1	43.5	47.3	51.7
780	39.6	39.6	39.6	39.6	39.6	39.6	39.7	39.7	39.9	40.1	40.9	44.1	47.8	51.9
800	40.4	40.4	40.4	40.4	40.4	40.4	40.4	40.5	40.6	40.9	41.6	44.7	48.2	52.1

From ASME International Steam Tables for Industrial Use.