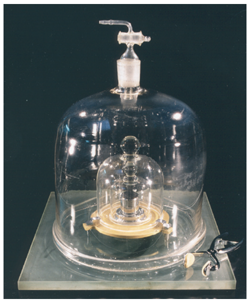
Collage carte SI

The International System of Units, the SI, is the internationally agreed basis for expressing measurements at all levels of precision and in all areas of science, technology, and human endeavour.



The international prototype of the kilogram, $\mathcal{K}$, the only remaining artefact used to define a base unit of the SI.

Base units of the SI

There are two classes of units in the SI, base units and derived units. The seven **base units** of the SI, listed in the table on the right alongside their corresponding **base quantities**, provide the reference used to define all the measurement units of the International System.

Derived units

Derived units are defined as products of powers of the base units and are used to measure **derived quantities.**

Some examples of derived quantities and units

Derived quantity, symbol	Derived unit, symbol
area, A	square metre, m^2
volume, V	cubic metre, m^3
speed, velocity, v	metre per second, m/s
acceleration, a	metre per second squared, m/s^2
mass density, ρ	kilogram per cubic metre, kg/m^3
current density, j	ampere per square metre, A/m^2
magnetic field strength, H	ampere per metre, A/m
concentration, c	mole per cubic metre, mol/m^3
luminance, L_v	candela per square metre, cd/m^2
refractive index, n	(the number) one

The seven base units of the SI

Quantity	**Base unit, symbol:** definition of unit
length	**metre, m:** The metre is the length of the path travelled by light in vacuum during a time interval of 1/299 792 458 of a second.
mass	**kilogram, kg:** The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
time, duration	**second, s:** 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 caesium 133 atom.
electric current	**ampere, A:** 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 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.
thermodynamic temperature	**kelvin, K:** The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
amount of substance	**mole, mol:** 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. 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.
luminous intensity	**candela, cd:** 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.

Dimensionless quantities, also called **quantities of dimension one**, are usually defined as the ratio of two quantities of the same kind (for example, refractive index, in the table on the left, is the ratio of two speeds). Thus the unit of a dimensionless quantity is the ratio of two identical SI units, and is therefore always equal to one. However in expressing the values of dimensionless quantities the unit one, 1, is not written.

Some derived units are given a **special name**, this being simply a compact form for the expression of combinations of base units that are used frequently. There are 22 special names for units approved for use in the SI.

Derived units with special names in the SI

Derived quantity	Name of derived unit	Symbol for unit	Expression in terms of other units
plane angle	radian	rad	m/m = 1
solid angle	steradian	sr	$m^2/m^2 = 1$
frequency	hertz	Hz	s^{-1}
force	newton	N	$m\ kg\ s^{-2}$
pressure, stress	pascal	Pa	$N/m^2 = m^{-1}\ kg\ s^{-2}$
energy, work, amount of heat	joule	J	$N\ m = m^2\ kg\ s^{-2}$
power, radiant flux	watt	W	$J/s = m^2\ kg\ s^{-3}$
electric charge	coulomb	C	s A
electric potential difference	volt	V	$W/A = m^2\ kg\ s^{-3} A^{-1}$
capacitance	farad	F	$C/V = m^{-2}\ kg^{-1}\ s^4\ A^2$
electric resistance	ohm	Ω	$V/A = m^2\ kg\ s^{-3}\ A^{-2}$
electric conductance	siemens	S	$A/V = m^{-2}\ kg^{-1}\ s^3\ A^2$
magnetic flux	weber	Wb	$V\ s = m^2\ kg\ s^{-2} A^{-1}$
magnetic flux density	tesla	T	$Wb/m^2 = kg\ s^{-2}\ A^{-1}$
inductance	henry	H	$Wb/A = m^2\ kg\ s^{-2}\ A^{-2}$
Celsius temperature	degree Celsius	°C	K
luminous flux	lumen	lm	cd sr = cd
illuminance	lux	lx	$lm/m^2 = m^{-2}\ cd$
activity referred to a radionuclide	becquerel	Bq	s^{-1}
absorbed dose	gray	Gy	$J/kg = m^2\ s^{-2}$
dose equivalent	sievert	Sv	$J/kg = m^2\ s^{-2}$
catalytic activity	katal	kat	$s^{-1}\ mol$

Although the hertz and the becquerel are both equal to the reciprocal second, the hertz is only used for cyclic phenomena, and the becquerel for stochastic processes in radioactive decay.

The unit of Celsius temperature is the degree Celsius, °C, which is equal in magnitude to the kelvin, K. The quantity Celsius temperature, t, is related to thermodynamic temperature, T, by the equation:

$$t/°\text{C} = T/\text{K} - 273.15.$$

Decimal multiples and sub-multiples of SI units

A set of multiple and sub-multiple **prefixes** have been adopted for use with the SI units. They may be used with any of the base units and with any of the derived units with special names.

The SI prefixes

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

When the prefixes are used, the prefix name and the unit name are combined to form a single word, and similarly the prefix symbol and the unit symbol are written without any space to form a single symbol, which may itself be raised to any power.
For example, we may write: kilometre, km; microvolt, µV; 50 V/cm = 50 V $(10^{-2}\,\text{m})^{-1}$ = 5000 V/m.

The kilogram, kg, is an exception, because although it is a base unit the name already includes the prefix kilo, for historical reasons. Multiples and sub-multiples of the kilogram are written by combining prefixes with the gram: thus we write milligram, mg, not microkilogram, µkg.

Units outside the SI

The SI is the only system of units that is universally recognized, so that it has a distinct advantage in establishing a dialogue over the whole world. Nonetheless, for historical reasons some non-SI units are still widely used to meet the needs of special interest groups, or because there is no convenient SI alternative. It will always remain the prerogative of a scientist to use the units that he or she considers to be best suited to the purpose. However when non-SI units are used, the conversion factor to the SI should be quoted (with a few exceptions of very familiar non-SI units).

Some of the most important and familiar non-SI units approved for use with the SI are the minute, symbol min, the hour, symbol h, and the day, symbol d, as units of time.

Using the SI to express the values of quantities

The **value of a quantity** is written as the product of a number and a unit. One space is always left between the number and the unit. The numerical value depends on the choice of unit, so that the same value of a quantity may have different numerical values when expressed in different units. For example, the value of the speed of a bicycle might be v = 5.0 m/s = 18 km/h.

Quantity symbols are printed in an italic (slanting) type. Either capital or lower case letters may be used.

Unit symbols are printed in a roman (upright) type, regardless of the type used in the surrounding text. They are mathematical entities and not abbreviations; they are never followed by a stop (except at the end of a sentence) nor by an s for the plural. They are written in lower case letters, except that the first letter is a capital when the unit is named for an individual (for example, ampere, A; kelvin, K; hertz, Hz; coulomb, C; but metre, m; second, s). The use of the correct form for unit symbols is mandatory.

For each quantity, there is only one SI unit. However the same SI unit may be used to express the values of several different quantities. For example, the J/K is the SI unit of both heat capacity and entropy. It is therefore important not to use the unit alone to specify the quantity.

The decimal marker may be either a point (i.e. a stop) or a comma, as is customary in the language of the surrounding text.

When a number has many digits, it is customary to group the digits into threes about the decimal point for easy reading, using a (thin) space; neither a point nor a comma should be used.

Because units symbols are mathematical entities, they may be treated by the ordinary rules of algebra. For example, the equation T = 293 K may equally be written T/K = 293. This procedure is described as the use of quantity calculus, or the algebra of quantities. It is often useful to use the ratio of a quantity to its unit for heading the columns of a table, or labelling the axes of a graph, so that the entries in the table or the labels of the tick marks on the axes are all simply numbers.

For further information
see the website
of the Bureau International
des Poids et Mesures,
BIPM, at
www.bipm.org

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Collage carte BIPM

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2 SI units

2.1 SI base units

Formal definitions of all SI base units are adopted by the CGPM. The first two definitions were adopted in 1889, and the most recent in 1983. These definitions are modified from time to time as science advances.

2.1.1 Definitions

Current definitions of the base units, as taken from the *Comptes Rendus* (CR) of the corresponding CGPM, are shown below indented and in a heavy sans-serif font. Related decisions which clarify these definitions but are not formally part of them, as taken from the *Comptes Rendus* of the corresponding CGPM or the *Procès-Verbaux* (PV) of the CIPM, are also shown indented but in a sans-serif font of normal weight. The linking text provides historical notes and explanations, but is not part of the definitions themselves.

It is important to distinguish between the definition of a unit and its realization. The definition of each base unit of the SI is carefully drawn up so that it is unique and provides a sound theoretical basis upon which the most accurate and reproducible measurements can be made. The realization of the definition of a unit is the procedure by which the definition may be used to establish the value and associated uncertainty of a quantity of the same kind as the unit. A description of how the definitions of some important units are realized in practice is given on the BIPM website,

www.bipm.org/en/si/si_brochure/appendix2/.

A coherent SI derived unit is defined uniquely only in terms of SI base units. For example, the coherent SI derived unit of resistance, the ohm, symbol Ω, is uniquely defined by the relation $\Omega = \mathrm{m}^2\ \mathrm{kg}\ \mathrm{s}^{-3}\ \mathrm{A}^{-2}$, which follows from the definition of the quantity electrical resistance. However any method consistent with the laws of physics could be used to realize any SI unit. For example, the unit ohm can be realized with high accuracy using the quantum Hall effect and the value of the von Klitzing constant recommended by the CIPM (see pp. 163 and 166, respectively, Appendix 1).

Finally, it should be recognized that although the seven base quantities – length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity – are by convention regarded as independent, their respective base units – the metre, kilogram, second, ampere, kelvin, mole, and candela – are in a number of instances interdependent. Thus the definition of the metre incorporates the second; the definition of the ampere incorporates the metre, kilogram, and second; the definition of the mole incorporates the kilogram; and the definition of the candela incorporates the metre, kilogram, and second.

2.1.1.1 Unit of length (metre)

The 1889 definition of the metre, based on the international prototype of platinum-iridium, was replaced by the 11th CGPM (1960) using a definition based on the wavelength of krypton 86 radiation. This change was adopted in order to improve the accuracy with which the definition of the metre could be realized, the realization being achieved using an interferometer with a travelling microscope to measure the optical path difference as the fringes were counted. In turn, this was replaced in 1983 by the 17th CGPM (1983, Resolution 1, CR, 97, and *Metrologia*, 1984, **20**, 25) that specified the current definition, as follows:

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

It follows that the speed of light in vacuum is exactly 299 792 458 metres per second, $c_0 = 299\ 792\ 458$ m/s.

The symbol, c_0 (or sometimes simply c), is the conventional symbol for the speed of light in vacuum.

The original international prototype of the metre, which was sanctioned by the 1st CGPM in 1889 (CR, 34-38), is still kept at the BIPM under conditions specified in 1889.

2.1.1.2 Unit of mass (kilogram)

The international prototype of the kilogram, an artefact made of platinum-iridium, is kept at the BIPM under the conditions specified by the 1st CGPM in 1889 (CR, 34-38) when it sanctioned the prototype and declared:

> This prototype shall henceforth be considered to be the unit of mass.

The 3rd CGPM (1901, CR, 70), in a declaration intended to end the ambiguity in popular usage concerning the use of the word “weight”, confirmed that:

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

The complete declaration appears on p. 143.

It follows that the mass of the international prototype of the kilogram is always 1 kilogram exactly, $m(\mathcal{K}) = 1$ kg. However, due to the inevitable accumulation of contaminants on surfaces, the international prototype is subject to reversible surface contamination that approaches 1 μg per year in mass. For this reason, the CIPM declared that, pending further research, the reference mass of the international prototype is that immediately after cleaning and washing by a specified method (PV, 1989, **57**, 104-105 and PV, 1990, **58**, 95-97). The reference mass thus defined is used to calibrate national standards of platinum-iridium alloy (*Metrologia*, 1994, **31**, 317-336).

The symbol, $m(\mathcal{K})$, is used to denote the mass of the international prototype of the kilogram, $\mathcal{K}$.

2.1.1.3 Unit of time (second)

The unit of time, the second, was at one time considered to be the fraction 1/86 400 of the mean solar day. The exact definition of “mean solar day” was left to the astronomers. However measurements showed that irregularities in the rotation of the Earth made this an unsatisfactory definition. In order to define the unit of time more precisely, the 11th CGPM (1960, Resolution 9; CR, 86) adopted a definition given by the International Astronomical Union based on the tropical year 1900. Experimental work, however, had already shown that an atomic standard of time, based on a transition between two energy levels of an atom or a molecule, could be realized and reproduced much more accurately. Considering that a very precise definition of the unit of time is indispensable for science and technology, the 13th CGPM (1967/68, Resolution 1; CR, 103 and *Metrologia*, 1968, **4**, 43) replaced the definition of the second by the following:

> **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 caesium 133 atom.**

It follows that the hyperfine splitting in the ground state of the caesium 133 atom is exactly 9 192 631 770 hertz, $\nu(\text{hfs Cs}) = 9\,192\,631\,770$ Hz.

The symbol, $\nu(\text{hfs Cs})$, is used to denote the frequency of the hyperfine transition in the ground state of the caesium atom.

At its 1997 meeting the CIPM affirmed that:

> This definition refers to a caesium atom at rest at a temperature of 0 K.

This note was intended to make it clear that the definition of the SI second is based on a caesium atom unperturbed by black body radiation, that is, in an environment whose thermodynamic temperature is 0 K. The frequencies of all primary frequency standards should therefore be corrected for the shift due to ambient radiation, as stated at the meeting of the Consultative Committee for Time and Frequency in 1999.

2.1.1.4 Unit of electric current (ampere)

Electric units, called "international units", for current and resistance, were introduced by the International Electrical Congress held in Chicago in 1893, and definitions of the "international ampere" and "international ohm" were confirmed by the International Conference in London in 1908.

Although it was already obvious on the occasion of the 8th CGPM (1933) that there was a unanimous desire to replace those "international units" by so-called "absolute units", the official decision to abolish them was only taken by the 9th CGPM (1948), which adopted the ampere for the unit of electric current, following a definition proposed by the CIPM (1946, Resolution 2; PV, **20**, 129-137):

> **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 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.**

It follows that the magnetic constant, μ_0, also known as the permeability of free space, is exactly $4\pi \times 10^{-7}$ henries per metre, $\mu_0 = 4\pi \times 10^{-7}$ H/m.

The expression "MKS unit of force" which occurs in the original text of 1946 has been replaced here by "newton", a name adopted for this unit by the 9th CGPM (1948, Resolution 7; CR, 70).

2.1.1.5 Unit of thermodynamic temperature (kelvin)

The definition of the unit of thermodynamic temperature was given in substance by the 10th CGPM (1954, Resolution 3; CR, 79) which selected the triple point of water as the fundamental fixed point and assigned to it the temperature 273.16 K, so defining the unit. The 13th CGPM (1967/68, Resolution 3; CR, 104 and *Metrologia*, 1968, **4**, 43) adopted the name kelvin, symbol K, instead of "degree Kelvin", symbol °K, and defined the unit of thermodynamic temperature as follows (1967/68, Resolution 4; CR, 104 and *Metrologia*, 1968, **4**, 43):

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

It follows that the thermodynamic temperature of the triple point of water is exactly 273.16 kelvins, $T_{\mathrm{tpw}} = 273.16$ K.

The symbol, T_{tpw}, is used to denote the thermodynamic temperature of the triple point of water.

At its 2005 meeting the CIPM affirmed that:

> This definition refers to water having the isotopic composition defined exactly by the following amount of substance ratios: 0.000 155 76 mole of ^{2}H per mole of ^{1}H, 0.000 379 9 mole of ^{17}O per mole of ^{16}O, and 0.002 005 2 mole of ^{18}O per mole of ^{16}O.

Because of the manner in which temperature scales used to be defined, it remains common practice to express a thermodynamic temperature, symbol T, in terms of its difference from the reference temperature $T_0 = 273.15$ K, the ice point. This difference is called the Celsius temperature, symbol t, which is defined by the quantity equation:

$$t = T - T_0.$$

The unit of Celsius temperature is the degree Celsius, symbol °C, which is by definition equal in magnitude to the kelvin. A difference or interval of temperature may be expressed in kelvins or in degrees Celsius (13th CGPM, 1967/68, Resolution 3, mentioned above), the numerical value of the temperature difference being the same. However, the numerical value of a Celsius temperature expressed in degrees Celsius is related to the numerical value of the thermodynamic temperature expressed in kelvins by the relation

$$t/^\circ\mathrm{C} = T/\mathrm{K} - 273.15.$$

The kelvin and the degree Celsius are also units of the International Temperature Scale of 1990 (ITS-90) adopted by the CIPM in 1989 in its Recommendation 5 (CI-1989; PV, **57**, 115 and *Metrologia*, 1990, **27**, 13).

2.1.1.6 Unit of amount of substance (mole)

Following the discovery of the fundamental laws of chemistry, units called, for example, "gram-atom" and "gram-molecule", were used to specify amounts of chemical elements or compounds. These units had a direct connection with "atomic weights" and "molecular weights", which are in fact relative masses. "Atomic weights" were originally referred to the atomic weight of oxygen, by general agreement taken as 16. But whereas physicists separated the isotopes in a mass spectrometer and attributed the value 16 to one of the isotopes of oxygen, chemists attributed the same value to the (slightly variable) mixture of isotopes 16, 17 and 18, which was for them the naturally occurring element oxygen. Finally an agreement between the International Union of Pure and Applied Physics (IUPAP) and the International Union of Pure and Applied Chemistry (IUPAC) brought this duality to an end in 1959/60. Physicists and chemists have ever since agreed to assign the value 12, exactly, to the so-called atomic weight of the isotope of carbon with mass number 12 (carbon 12, ^{12}C), correctly called the relative atomic mass $A_\mathrm{r}(^{12}\mathrm{C})$. The unified scale thus obtained gives the relative atomic and molecular masses, also known as the atomic and molecular weights, respectively.

The recommended symbol for relative atomic mass (atomic weight) is $A_\mathrm{r}(\mathrm{X})$, where the atomic entity X should be specified, and for relative molecular mass of a molecule (molecular weight) it is $M_\mathrm{r}(\mathrm{X})$, where the molecular entity X should be specified.

The quantity used by chemists to specify the amount of chemical elements or compounds is now called "amount of substance". Amount of substance is defined to be proportional to the number of specified elementary entities in a sample, the proportionality constant being a universal constant which is the same for all samples. The unit of amount of substance is called the *mole*, symbol mol, and the mole is defined by specifying the mass of carbon 12 that constitutes one mole of carbon 12 atoms. By international agreement this was fixed at 0.012 kg, i.e. 12 g.

Following proposals by the IUPAP, the IUPAC, and the ISO, the CIPM gave a definition of the mole in 1967 and confirmed it in 1969. This was adopted by the 14th CGPM (1971, Resolution 3; CR, 78 and *Metrologia*, 1972, **8**, 36):

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; its symbol is "mol".**
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.**

It follows that the molar mass of carbon 12 is exactly 12 grams per mole, $M(^{12}\mathrm{C}) = 12$ g/mol.

The molar mass of an atom or molecule X is denoted $M(\mathrm{X})$ or M_X, and is the mass per mole of X.

In 1980 the CIPM approved the report of the CCU (1980) which specified that

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

When the definition of the mole is quoted, it is conventional also to include this remark.

The definition of the mole also determines the value of the universal constant that relates the number of entities to amount of substance for any sample. This constant is called the Avogadro constant, symbol N_A or L. If $N(\mathrm{X})$ denotes the number of entities X in a specified sample, and if $n(\mathrm{X})$ denotes the amount of substance of entities X in the same sample, the relation is

$$n(\mathrm{X}) = N(\mathrm{X})/N_\mathrm{A}.$$

Note that since $N(\mathrm{X})$ is dimensionless, and $n(\mathrm{X})$ has the SI unit mole, the Avogadro constant has the coherent SI unit reciprocal mole.

In the name "amount of substance", the words "of substance" could for simplicity be replaced by words to specify the substance concerned in any particular application, so that one may, for example, talk of "amount of hydrogen chloride, HCl", or "amount of benzene, C_6H_6". It is important to always give a precise specification of the entity involved (as emphasized in the second sentence of the definition of the mole); this should preferably be done by giving the empirical chemical formula of the material involved. Although the word "amount" has a more general dictionary definition, this abbreviation of the full name "amount of substance" may be used for brevity. This also applies to derived quantities such as "amount of substance concentration", which may simply be called "amount concentration". However, in the field of clinical chemistry the name "amount of substance concentration" is generally abbreviated to "substance concentration".

2.1.1.7 Unit of luminous intensity (candela)

The units of luminous intensity based on flame or incandescent filament standards in use in various countries before 1948 were replaced initially by the "new candle" based on the luminance of a Planck radiator (a black body) at the temperature of freezing platinum. This modification had been prepared by the International Commission on Illumination (CIE) and by the CIPM before 1937, and the decision was promulgated by the CIPM in 1946. It was then ratified in 1948 by the 9th CGPM which adopted a new international name for this unit, the *candela*, symbol cd; in

1967 the 13th CGPM (Resolution 5, CR, 104 and *Metrologia*, 1968, **4**, 43-44) gave an amended version of this definition.

In 1979, because of the difficulties in realizing a Planck radiator at high temperatures, and the new possibilities offered by radiometry, i.e. the measurement of optical radiation power, the 16th CGPM (1979, Resolution 3; CR, 100 and *Metrologia*, 1980, **16**, 56) adopted a new definition of the candela:

> **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.**

It follows that the spectral luminous efficacy for monochromatic radiation of frequency of 540×10^{12} hertz is exactly 683 lumens per watt, $K = 683$ lm/W = 683 cd sr/W.

2.1.2 Symbols for the seven base units

The base units of the International System are listed in Table 1, which relates the base quantity to the unit name and unit symbol for each of the seven base units (10th CGPM (1954, Resolution 6; CR, 80); 11th CGPM (1960, Resolution 12; CR, 87); 13th CGPM (1967/68, Resolution 3; CR, 104 and *Metrologia*, 1968, **4**, 43); 14th CGPM (1971, Resolution 3; CR, 78 and *Metrologia*, 1972, **8**, 36)).

Table 1. SI base units

Base quantity		SI base unit	
Name	Symbol	Name	Symbol
length	l, x, r, etc.	metre	m
mass	m	kilogram	kg
time, duration	t	second	s
electric current	I, i	ampere	A
thermodynamic temperature	T	kelvin	K
amount of substance	n	mole	mol
luminous intensity	I_v	candela	cd

The symbols for quantities are generally single letters of the Latin or Greek alphabets, printed in an italic font, and are *recommendations*.

The symbols for units are *mandatory*, see chapter 5.

2.2 SI derived units

Derived units are products of powers of base units. Coherent derived units are products of powers of base units that include no numerical factor other than 1. The base and coherent derived units of the SI form a coherent set, designated the set of *coherent SI units* (see 1.4, p. 106).

2.2.1 Derived units expressed in terms of base units

The number of quantities in science is without limit, and it is not possible to provide a complete list of derived quantities and derived units. However, Table 2 lists some examples of derived quantities, and the corresponding coherent derived units expressed directly in terms of base units.

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

Derived quantity		SI coherent derived unit	
Name	Symbol	Name	Symbol
area	A	square metre	m^2
volume	V	cubic metre	m^3
speed, velocity	v	metre per second	m/s
acceleration	a	metre per second squared	$\mathrm{m/s}^2$
wavenumber	σ, $\tilde{\nu}$	reciprocal metre	m^{-1}
density, mass density	ρ	kilogram per cubic metre	$\mathrm{kg/m}^3$
surface density	ρ_A	kilogram per square metre	$\mathrm{kg/m}^2$
specific volume	v	cubic metre per kilogram	$\mathrm{m}^3\mathrm{/kg}$
current density	j	ampere per square metre	$\mathrm{A/m}^2$
magnetic field strength	H	ampere per metre	A/m
amount concentration [(a)], concentration	c	mole per cubic metre	$\mathrm{mol/m}^3$
mass concentration	ρ, γ	kilogram per cubic metre	$\mathrm{kg/m}^3$
luminance	L_v	candela per square metre	$\mathrm{cd/m}^2$
refractive index [(b)]	n	one	1
relative permeability [(b)]	μ_r	one	1

(*a*) In the field of clinical chemistry this quantity is also called substance concentration.

(*b*) These are dimensionless quantities, or quantities of dimension one, and the symbol “1” for the unit (the number “one”) is generally omitted in specifying the values of dimensionless quantities.

2.2.2 Units with special names and symbols; units that incorporate special names and symbols

For convenience, certain coherent derived units have been given special names and symbols. There are 22 such units, as listed in Table 3. These special names and symbols may themselves be used in combination with the names and symbols for base units and for other derived units to express the units of other derived quantities. Some examples are given in Table 4. The special names and symbols are simply a compact form for the expression of combinations of base units that are used frequently, but in many cases they also serve to remind the reader of the quantity involved. The SI prefixes may be used with any of the special names and symbols, but when this is done the resulting unit will no longer be coherent.

Among these names and symbols the last four entries in Table 3 are of particular note since they were adopted by the 15th CGPM (1975, Resolutions 8 and 9; CR, 105 and *Metrologia*, 1975, **11**, 180), the 16th CGPM (1979, Resolution 5; CR, 100 and *Metrologia*, 1980, **16**, 56) and the 21st CGPM (1999, Resolution 12; CR, 334-335 and *Metrologia*, 2000, **37**, 95) specifically with a view to safeguarding human health.

In both Tables 3 and 4 the final column shows how the SI units concerned may be expressed in terms of SI base units. In this column factors such as m^0, kg^0, etc., which are all equal to 1, are not shown explicitly.

Table 3. Coherent derived units in the SI with special names and symbols

	SI coherent derived unit (*a*)			
Derived quantity	Name	Symbol	Expressed in terms of other SI units	Expressed in terms of SI base units
plane angle	radian (*b*)	rad	1 (*b*)	$\mathrm{m/m}$
solid angle	steradian (*b*)	sr (*c*)	1 (*b*)	$\mathrm{m^2/m^2}$
frequency	hertz (*d*)	Hz		$\mathrm{s^{-1}}$
force	newton	N		$\mathrm{m\ kg\ s^{-2}}$
pressure, stress	pascal	Pa	$\mathrm{N/m^2}$	$\mathrm{m^{-1}\ kg\ s^{-2}}$
energy, work, amount of heat	joule	J	N m	$\mathrm{m^2\ kg\ s^{-2}}$
power, radiant flux	watt	W	J/s	$\mathrm{m^2\ kg\ s^{-3}}$
electric charge, amount of electricity	coulomb	C		s A
electric potential difference, electromotive force	volt	V	W/A	$\mathrm{m^2\ kg\ s^{-3}\ A^{-1}}$
capacitance	farad	F	C/V	$\mathrm{m^{-2}\ kg^{-1}\ s^4\ A^2}$
electric resistance	ohm	Ω	V/A	$\mathrm{m^2\ kg\ s^{-3}\ A^{-2}}$
electric conductance	siemens	S	A/V	$\mathrm{m^{-2}\ kg^{-1}\ s^3\ A^2}$
magnetic flux	weber	Wb	V s	$\mathrm{m^2\ kg\ s^{-2}\ A^{-1}}$
magnetic flux density	tesla	T	$\mathrm{Wb/m^2}$	$\mathrm{kg\ s^{-2}\ A^{-1}}$
inductance	henry	H	Wb/A	$\mathrm{m^2\ kg\ s^{-2}\ A^{-2}}$
Celsius temperature	degree Celsius (*e*)	°C		K
luminous flux	lumen	lm	cd sr (*c*)	cd
illuminance	lux	lx	$\mathrm{lm/m^2}$	$\mathrm{m^{-2}\ cd}$
activity referred to a radionuclide (*f*)	becquerel (*d*)	Bq		$\mathrm{s^{-1}}$
absorbed dose, specific energy (imparted), kerma	gray	Gy	J/kg	$\mathrm{m^2\ s^{-2}}$
dose equivalent, ambient dose equivalent, directional dose equivalent, personal dose equivalent	sievert (*g*)	Sv	J/kg	$\mathrm{m^2\ s^{-2}}$
catalytic activity	katal	kat		$\mathrm{s^{-1}\ mol}$

(*a*) The SI prefixes may be used with any of the special names and symbols, but when this is done the resulting unit will no longer be coherent.

(*b*) The radian and steradian are special names for the number one that may be used to convey information about the quantity concerned. In practice the symbols rad and sr are used where appropriate, but the symbol for the derived unit one is generally omitted in specifying the values of dimensionless quantities.

(*c*) In photometry the name steradian and the symbol sr are usually retained in expressions for units.

(*d*) The hertz is used only for periodic phenomena, and the becquerel is used only for stochastic processes in activity referred to a radionuclide.

(*e*) The degree Celsius is the special name for the kelvin used to express Celsius temperatures. The degree Celsius and the kelvin are equal in size, so that the numerical value of a temperature difference or temperature interval is the same when expressed in either degrees Celsius or in kelvins.

(*f*) Activity referred to a radionuclide is sometimes incorrectly called radioactivity.

(*g*) See CIPM Recommendation 2 (CI-2002), p. 168, on the use of the sievert (PV, 2002, **70**, 205).

Table 4. Examples of SI coherent derived units whose names and symbols include SI coherent derived units with special names and symbols

	SI coherent derived unit		
Derived quantity	Name	Symbol	Expressed in terms of SI base units
dynamic viscosity	pascal second	Pa s	m^{-1} kg s^{-1}
moment of force	newton metre	N m	m^2 kg s^{-2}
surface tension	newton per metre	N/m	kg s^{-2}
angular velocity	radian per second	rad/s	m m^{-1} $s^{-1} = s^{-1}$
angular acceleration	radian per second squared	rad/s^2	m m^{-1} $s^{-2} = s^{-2}$
heat flux density, irradiance	watt per square metre	W/m^2	kg s^{-3}
heat capacity, entropy	joule per kelvin	J/K	m^2 kg s^{-2} K^{-1}
specific heat capacity, specific entropy	joule per kilogram kelvin	J/(kg K)	m^2 s^{-2} K^{-1}
specific energy	joule per kilogram	J/kg	m^2 s^{-2}
thermal conductivity	watt per metre kelvin	W/(m K)	m kg s^{-3} K^{-1}
energy density	joule per cubic metre	J/m^3	m^{-1} kg s^{-2}
electric field strength	volt per metre	V/m	m kg s^{-3} A^{-1}
electric charge density	coulomb per cubic metre	C/m^3	m^{-3} s A
surface charge density	coulomb per square metre	C/m^2	m^{-2} s A
electric flux density, electric displacement	coulomb per square metre	C/m^2	m^{-2} s A
permittivity	farad per metre	F/m	m^{-3} kg^{-1} s^4 A^2
permeability	henry per metre	H/m	m kg s^{-2} A^{-2}
molar energy	joule per mole	J/mol	m^2 kg s^{-2} mol^{-1}
molar entropy, molar heat capacity	joule per mole kelvin	J/(mol K)	m^2 kg s^{-2} $K^{-1}mol^{-1}$
exposure (x- and γ-rays)	coulomb per kilogram	C/kg	kg^{-1} s A
absorbed dose rate	gray per second	Gy/s	m^2 s^{-3}
radiant intensity	watt per steradian	W/sr	m^4 m^{-2} kg $s^{-3} = m^2$ kg s^{-3}
radiance	watt per square metre steradian	W/(m^2 sr)	m^2 m^{-2} kg s^{-3} = kg s^{-3}
catalytic activity concentration	katal per cubic metre	kat/m^3	m^{-3} s^{-1} mol

The values of several different quantities may be expressed using the same name and symbol for the SI unit. Thus for the quantity heat capacity as well as the quantity entropy, the SI unit is the joule per kelvin. Similarly for the base quantity electric current as well as the derived quantity magnetomotive force, the SI unit is the ampere. It is therefore important not to use the unit alone to specify the quantity. This applies not only to scientific and technical texts, but also, for example, to measuring instruments (i.e. an instrument read-out should indicate both the unit and the quantity measured).

A derived unit can often be expressed in different ways by combining base units with derived units having special names. Joule, for example, may formally be written newton metre, or kilogram metre squared per second squared. This, however, is an algebraic freedom to be governed by common sense physical considerations; in a given situation some forms may be more helpful than others.

In practice, with certain quantities, preference is given to the use of certain special unit names, or combinations of unit names, to facilitate the distinction between different quantities having the same dimension. When using this freedom, one may recall the process by which the quantity is defined. For example, the quantity torque may be thought of as the cross product of force and distance, suggesting the unit newton metre, or it may be thought of as energy per angle, suggesting the unit joule per radian. The SI unit of frequency is given as the hertz, implying the unit cycles per second; the SI unit of angular velocity is given as the radian per second; and the SI unit of activity is designated the becquerel, implying the unit counts per second. Although it would be formally correct to write all three of these units as the reciprocal second, the use of the different names emphasises the different nature of the quantities concerned. Using the unit radian per second for angular velocity, and hertz for frequency, also emphasizes that the numerical value of the angular velocity in radian per second is 2π times the numerical value of the corresponding frequency in hertz.

In the field of ionizing radiation, the SI unit of activity is designated the becquerel rather than the reciprocal second, and the SI units of absorbed dose and dose equivalent are designated the gray and the sievert, respectively, rather than the joule per kilogram. The special names becquerel, gray, and sievert were specifically introduced because of the dangers to human health that might arise from mistakes involving the units reciprocal second and joule per kilogram, in case the latter units were incorrectly taken to identify the different quantities involved.

The CIPM, recognizing the particular importance of the health-related units, adopted a detailed text on the sievert for the 5th edition of this Brochure: Recommendation 1 (CI-1984), adopted by the CIPM (PV, 1984, **52**, 31 and *Metrologia*, 1985, **21**, 90), and Recommendation 2 (CI-2002), adopted by the CIPM (PV, **70**, 205), see pp. 161 and 168, respectively.

2.2.3 Units for dimensionless quantities, also called quantities of dimension one

Certain quantities are defined as the ratio of two quantities of the same kind, and are thus dimensionless, or have a dimension that may be expressed by the number one. The coherent SI unit of all such dimensionless quantities, or quantities of dimension one, is the number one, since the unit must be the ratio of two identical SI units. The values of all such quantities are simply expressed as numbers, and the unit one is not explicitly shown. Examples of such quantities are refractive index, relative permeability, and friction factor. There are also some quantities that are defined as a more complex product of simpler quantities in such a way that the product is dimensionless. Examples include the “characteristic numbers” like the Reynolds number $Re = \rho v l/\eta$, where ρ is mass density, η is dynamic viscosity, v is speed, and l is length. For all these cases the unit may be considered as the number one, which is a dimensionless derived unit.

Another class of dimensionless quantities are numbers that represent a count, such as a number of molecules, degeneracy (number of energy levels), and partition function in statistical thermodynamics (number of thermally accessible states). All of these counting quantities are also described as being dimensionless, or of dimension one, and are taken to have the SI unit one, although the unit of counting quantities cannot be described as a derived unit expressed in terms of the base units of the SI. For such quantities, the unit one may instead be regarded as a further base unit.

In a few cases, however, a special name is given to the unit one, in order to facilitate the identification of the quantity involved. This is the case for the radian and the steradian. The radian and steradian have been identified by the CGPM as special names for the coherent derived unit one, to be used to express values of plane angle and solid angle, respectively, and are therefore included in Table 3.

3 Decimal multiples and submultiples of SI units

3.1 SI prefixes

The 11th CGPM (1960, Resolution 12; CR, 87) adopted a series of prefix names and prefix symbols to form the names and symbols of the decimal multiples and submultiples of SI units, ranging from 10^{12} to 10^{-12}. Prefixes for 10^{-15} and 10^{-18} were added by the 12th CGPM (1964, Resolution 8; CR, 94), for 10^{15} and 10^{18} by the 15th CGPM (1975, Resolution 10; CR, 106 and *Metrologia*, 1975, **11**, 180-181), and for 10^{21}, 10^{24}, 10^{-21} and 10^{-24} by the 19th CGPM (1991, Resolution 4; CR, 185 and *Metrologia*, 1992, **29**, 3). Table 5 lists all approved prefix names and symbols.

These SI prefixes refer strictly to powers of 10. They should not be used to indicate powers of 2 (for example, one kilobit represents 1000 bits and not 1024 bits). The IEC has adopted prefixes for binary powers in the international standard IEC 60027-2: 2005, third edition, *Letter symbols to be used in electrical technology – Part 2: Telecommunications and electronics.* The names and symbols for the prefixes corresponding to 2^{10}, 2^{20}, 2^{30}, 2^{40}, 2^{50}, and 2^{60} are, respectively: kibi, Ki; mebi, Mi; gibi, Gi; tebi, Ti; pebi, Pi; and exbi, Ei. Thus, for example, one kibibyte would be written: 1 KiB = 2^{10} B = 1024 B, where B denotes a byte. Although these prefixes are not part of the SI, they should be used in the field of information technology to avoid the incorrect usage of the SI prefixes.

Table 5. SI prefixes

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

Prefix symbols are printed in roman (upright) type, as are unit symbols, regardless of the type used in the surrounding text, and are attached to unit symbols without a space between the prefix symbol and the unit symbol. With the exception of da (deca), h (hecto), and k (kilo), all multiple prefix symbols are capital (upper case) letters, and all submultiple prefix symbols are lower case letters. All prefix names are printed in lower case letters, except at the beginning of a sentence.

Examples of the use of prefixes:
pm (picometre)
mmol (millimole)
GΩ (gigaohm)
THz (terahertz)

The grouping formed by a prefix symbol attached to a unit symbol constitutes a new inseparable unit symbol (forming a multiple or submultiple of the unit concerned) that can be raised to a positive or negative power and that can be combined with other unit symbols to form compound unit symbols.

Examples: $2.3\ \text{cm}^3 = 2.3\ (\text{cm})^3 = 2.3\ (10^{-2}\ \text{m})^3 = 2.3 \times 10^{-6}\ \text{m}^3$

$1\ \text{cm}^{-1} = 1\ (\text{cm})^{-1} = 1\ (10^{-2}\ \text{m})^{-1} = 10^{2}\ \text{m}^{-1} = 100\ \text{m}^{-1}$

$1\ \text{V/cm} = (1\ \text{V})/(10^{-2}\ \text{m}) = 10^{2}\ \text{V/m} = 100\ \text{V/m}$

$5000\ \mu\text{s}^{-1} = 5000\ (\mu\text{s})^{-1} = 5000\ (10^{-6}\ \text{s})^{-1} = 5 \times 10^{9}\ \text{s}^{-1}$

Similarly prefix names are also inseparable from the unit names to which they are attached. Thus, for example, millimetre, micropascal, and meganewton are single words.

Compound prefix symbols, that is, prefix symbols formed by the juxtaposition of two or more prefix symbols, are not permitted. This rule also applies to compound prefix names.

nm (nanometre), ***but not*** mµm (millimicrometre)

Prefix symbols can neither stand alone nor be attached to the number 1, the symbol for the unit one. Similarly, prefix names cannot be attached to the name of the unit one, that is, to the word "one."

The number of lead atoms in the sample is $N(\mathrm{Pb}) = 5 \times 10^6$, ***but not*** $N(\mathrm{Pb}) = 5$ M, where M is intended to be the prefix mega standing on its own.

Prefix names and symbols are used with a number of non-SI units (see Chapter 5), but they are never used with the units of time: minute, min; hour, h; day, d. However astronomers use milliarcsecond, which they denote mas, and microarcsecond, µas, which they use as units for measuring very small angles.

3.2 The kilogram

Among the base units of the International System, the kilogram is the only one whose name and symbol, for historical reasons, include a prefix. Names and symbols for decimal multiples and submultiples of the unit of mass are formed by attaching prefix names to the unit name "gram", and prefix symbols to the unit symbol "g" (CIPM 1967, Recommendation 2; PV, **35**, 29 and *Metrologia*, 1968, **4**, 45).

10^{-6} kg = 1 mg, ***but not*** 1 µkg (microkilogram)

4 Units outside the SI

The International System of Units, the SI, is a system of units, adopted by the CGPM, which provides the internationally agreed reference in terms of which all other units are now defined. It is recommended for use throughout science, technology, engineering, and commerce. The SI base units, and the SI coherent derived units, including those with special names, have the important advantage of forming a coherent set, with the effect that unit conversions are not required when inserting particular values for quantities into quantity equations. Because the SI is the only system of units that is globally recognized, it also has a clear advantage for establishing a worldwide dialogue. Finally, it simplifies the teaching of science and technology to the next generation if everyone uses this system.

Nonetheless it is recognized that some non-SI units still appear in the scientific, technical and commercial literature, and will continue to be used for many years. Some non-SI units are of historical importance in the established literature. Other non-SI units, such as the units of time and angle, are so deeply embedded in the history and culture of the human race that they will continue to be used for the foreseeable future. Individual scientists should also have the freedom to sometimes use non-SI units for which they see a particular scientific advantage in their work. An example of this is the use of CGS-Gaussian units in electromagnetic theory applied to quantum electrodynamics and relativity. For these reasons it is helpful to list some of the more important non-SI units, as is done below. However, if these units are used it should be understood that the advantages of the SI are lost.

The inclusion of non-SI units in this text does not imply that the use of non-SI units is to be encouraged. For the reasons already stated SI units are generally to be preferred. It is also desirable to avoid combining non-SI units with units of the SI; in particular, the combination of non-SI units with the SI to form compound units should be restricted to special cases in order not to compromise the advantages of the SI. Finally, when any of the non-SI units in Tables 7, 8, and 9 are used, it is good practice to define the non-SI unit in terms of the corresponding SI unit.

4.1 Non-SI units accepted for use with the SI, and units based on fundamental constants

The CIPM (2004) has revised the classification of non-SI units from that in the previous (7th) edition of this Brochure. Table 6 gives non-SI units that are accepted for use with the International System by the CIPM, because they are widely used with the SI in matters of everyday life. Their use is expected to continue indefinitely, and each has an exact definition in terms of an SI unit. Tables 7, 8 and 9 contain units that are used only in special circumstances. The units in Table 7 are related to fundamental constants, and their values have to be determined experimentally. Tables 8 and 9 contain units that have exactly defined values in terms of SI units, and are used in particular circumstances to satisfy the needs of commercial, legal, or specialized scientific interests. It is likely that these units will continue to be used for many years. Many of these units are also important for the interpretation of older scientific texts. Each of the Tables 6, 7, 8 and 9 is discussed in turn below.

Table 6 includes the traditional units of time and angle. It also contains the hectare, the litre, and the tonne, which are all in common everyday use throughout the world, and which differ from the corresponding coherent SI unit by an integer power of ten. The SI prefixes are used with several of these units, but not with the units of time.

Table 6. Non-SI units accepted for use with the International System of Units

Quantity	Name of unit	Symbol for unit	Value in SI units
time	minute	min	1 min = 60 s
	hour (*a*)	h	1 h = 60 min = 3600 s
	day	d	1 d = 24 h = 86 400 s
plane angle	degree (*b*, *c*)	°	$1^\circ = (\pi/180)$ rad
	minute	′	$1' = (1/60)^\circ = (\pi/10\,800)$ rad
	second (*d*)	″	$1'' = (1/60)' = (\pi/648\,000)$ rad
area	hectare (*e*)	ha	$1\ \mathrm{ha} = 1\ \mathrm{hm}^2 = 10^4\ \mathrm{m}^2$
volume	litre (*f*)	L, l	$1\ \mathrm{L} = 1\ \mathrm{l} = 1\ \mathrm{dm}^3 = 10^3\ \mathrm{cm}^3 = 10^{-3}\ \mathrm{m}^3$
mass	tonne (*g*)	t	$1\ \mathrm{t} = 10^3\ \mathrm{kg}$

(*a*) The symbol for this unit is included in Resolution 7 of the 9th CGPM (1948; CR, 70).

(*b*) ISO 31 recommends that the degree be divided decimally rather than using the minute and the second. For navigation and surveying, however, the minute has the advantage that one minute of latitude on the surface of the Earth corresponds (approximately) to one nautical mile.

(*c*) The gon (or grad, where grad is an alternative name for the gon) is an alternative unit of plane angle to the degree, defined as (π/200) rad. Thus there are 100 gon in a right angle. The potential value of the gon in navigation is that because the distance from the pole to the equator of the Earth is approximately 10 000 km, 1 km on the surface of the Earth subtends an angle of one centigon at the centre of the Earth. However the gon is rarely used.

(*d*) For applications in astronomy, small angles are measured in arcseconds (i.e. seconds of plane angle), denoted as or ″, milliarcseconds, microarcseconds, and picoarcseconds, denoted mas, μas, and pas, respectively, where arcsecond is an alternative name for second of plane angle.

(*e*) The unit hectare, and its symbol ha, were adopted by the CIPM in 1879 (PV, 1879, 41). The hectare is used to express land area.

(*f*) The litre, and the symbol lower-case l, were adopted by the CIPM in 1879 (PV, 1879, 41). The alternative symbol, capital L, was adopted by the 16th CGPM (1979, Resolution 6; CR, 101 and *Metrologia,* 1980, **16**, 56-57) in order to avoid the risk of confusion between the letter l (el) and the numeral 1 (one).

(*g*) The tonne, and its symbol t, were adopted by the CIPM in 1879 (PV, 1879, 41). In English speaking countries this unit is usually called “metric ton”.

Table 7 contains units whose values in SI units have to be determined experimentally, and thus have an associated uncertainty. Except for the astronomical unit, all other units in Table 7 are related to fundamental physical constants. The first three units, the non-SI units electronvolt, symbol eV, dalton or unified atomic mass unit, symbol Da or u, respectively, and the astronomical unit, symbol ua, have been accepted for use with the SI by the CIPM. The units in Table 7 play important roles in a number of specialized fields in which the results of measurements or calculations are most conveniently and usefully expressed in these units. For the electronvolt and the dalton the values depend on the elementary charge e and the Avogadro constant N_A, respectively.

There are many other units of this kind, because there are many fields in which it is most convenient to express the results of experimental observations or of theoretical calculations in terms of fundamental constants of nature. The two most important of such unit systems based on fundamental constants are the natural unit (n.u.) system used in high energy or particle physics, and the atomic unit (a.u.) system used in atomic physics and quantum chemistry. In the n.u. system, the base quantities for mechanics are speed, action, and mass, for which the base units are the speed of light in vacuum c_0, the Planck constant h divided by 2π, called the reduced Planck constant with symbol $\hbar$, and the mass of the electron m_e, respectively. In general these units are not given any special names or symbols but are simply called the n.u. of speed, symbol c_0, the n.u. of action, symbol $\hbar$, and the n.u. of mass, symbol m_e. In this system, time is a derived quantity and the n.u. of time is a derived unit equal to the combination of base units $\hbar/m_e c_0^2$. Similarly, in the a.u. system, any four of the five quantities charge, mass, action, length, and energy are taken as base quantities. The corresponding base units are the elementary charge e, electron mass m_e, action $\hbar$, Bohr radius (or bohr) a_0, and Hartree energy (or hartree) E_h, respectively. In this system, time is again a derived quantity and the a.u. of time a derived unit, equal to the combination of units $\hbar/E_h$. Note that $a_0 = \alpha/(4\pi R_\infty)$, where α is the fine-structure constant and R_∞ is the Rydberg constant; and $E_h = e^2/(4\pi\varepsilon_0 a_0) = 2R_\infty hc_0 = \alpha^2 m_e c_0^2$, where ε_0 is the electric constant and has an exact value in the SI.

For information, these ten natural and atomic units and their values in SI units are also listed in Table 7. Because the quantity systems on which these units are based differ so fundamentally from that on which the SI is based, they are not generally used with the SI, and the CIPM has not formally accepted them for use with the International System. To ensure understanding, the final result of a measurement or calculation expressed in natural or atomic units should also always be expressed in the corresponding SI unit. Natural units (n.u.) and atomic units (a.u.) are used only in their own special fields of particle and atomic physics, and quantum chemistry, respectively. Standard uncertainties in the least significant digits are shown in parenthesis after each numerical value.

Table 7. Non-SI units whose values in SI units must be obtained experimentally

Quantity	Name of unit	Symbol for unit	Value in SI units (a)
Units accepted for use with the SI			
energy	electronvolt (b)	eV	1 eV = 1.602 176 53 (14) × 10^{-19} J
mass	dalton, (c)	Da	1 Da = 1.660 538 86 (28) × 10^{-27} kg
	unified atomic mass unit	u	1 u = 1 Da
length	astronomical unit (d)	ua	1 ua = 1.495 978 706 91 (6) × 10^{11} m
Natural units (n.u.)			
speed	n.u. of speed (speed of light in vacuum)	c_0	299 792 458 m/s (exact)
action	n.u. of action (reduced Planck constant)	$\hbar$	1.054 571 68 (18) × 10^{-34} J s
mass	n.u. of mass (electron mass)	m_e	9.109 3826 (16) × 10^{-31} kg
time	n.u. of time	$\hbar/(m_e c_0^2)$	1.288 088 6677 (86) × 10^{-21} s
Atomic units (a.u.)			
charge	a.u. of charge, (elementary charge)	e	1.602 176 53 (14) × 10^{-19} C
mass	a.u. of mass, (electron mass)	m_e	9.109 3826 (16) × 10^{-31} kg
action	a.u. of action, (reduced Planck constant)	$\hbar$	1.054 571 68 (18) × 10^{-34} J s
length	a.u. of length, bohr (Bohr radius)	a_0	0.529 177 2108 (18) × 10^{-10} m
energy	a.u. of energy, hartree (Hartree energy)	E_h	4.359 744 17 (75) × 10^{-18} J
time	a.u. of time	$\hbar/E_h$	2.418 884 326 505 (16) × 10^{-17} s

(*a*) The values in SI units of all units in this table, except the astronomical unit, are taken from the 2002 CODATA set of recommended values of the fundamental physical constants, P.J. Mohr and B.N. Taylor, *Rev. Mod. Phys.*, 2005, **77**, 1-107. The standard uncertainty in the last two digits is given in parenthesis (see 5.3.5, p. 133).

(*b*) The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of one volt in vacuum. The electronvolt is often combined with the SI prefixes.

(*c*) The dalton (Da) and the unified atomic mass unit (u) are alternative names (and symbols) for the same unit, equal to 1/12 times the mass of a free carbon 12 atom, at rest and in its ground state. The dalton is often combined with SI prefixes, for example to express the masses of large molecules in kilodaltons, kDa, or megadaltons, MDa, or to express the values of small mass differences of atoms or molecules in nanodaltons, nDa, or even picodaltons, pDa.

(*d*) The astronomical unit is approximately equal to the mean Earth-Sun distance. It is the radius of an unperturbed circular Newtonian orbit about the Sun of a particle having infinitesimal mass, moving with a mean motion of 0.017 202 098 95 radians per day (known as the Gaussian constant). The value given for the astronomical unit is quoted from the IERS Conventions 2003 (D.D. McCarthy and G. Petit eds., *IERS Technical Note* 32, Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2004, 12). The value of the astronomical unit in metres comes from the JPL ephemerides DE403 (Standish E.M., Report of the IAU WGAS Sub-Group on Numerical Standards, *Highlights of Astronomy*, Appenzeller ed., Dordrecht: Kluwer Academic Publishers, 1995, 180-184).

Tables 8 and 9 contain non-SI units that are used by special interest groups for a variety of different reasons. Although the use of SI units is to be preferred for reasons already emphasized, authors who see a particular advantage in using these non-SI units should have the freedom to use the units that they consider to be best suited to their purpose. Since, however, SI units are the international meeting ground in terms of which all other units are defined, those who use units from Tables 8 and 9 should always give the definition of the units they use in terms of SI units.

Table 8 also gives the units of logarithmic ratio quantities, the neper, bel, and decibel. These are dimensionless units that are somewhat different in their nature from other dimensionless units, and some scientists consider that they should not even be called units. They are used to convey information on the nature of the logarithmic ratio quantity concerned. The neper, Np, is used to express the values of quantities whose numerical values are based on the use of the neperian (or natural) logarithm, $\ln = \log_e$. The bel and the decibel, B and dB, where 1 dB = (1/10) B, are used to express the values of logarithmic ratio quantities whose numerical values are based on the decadic logarithm, $\lg = \log_{10}$. The way in which these units are interpreted is described in footnotes (*g*) and (*h*) of Table 8. The numerical values of these units are rarely required. The units neper, bel, and decibel have been accepted by the CIPM for use with the International System, but are not considered as SI units.

The SI prefixes are used with two of the units in Table 8, namely, with the bar (e.g. millibar, mbar), and with the bel, specifically for the decibel, dB. The decibel is listed explicitly in the table because the bel is rarely used without the prefix.

Table 8. Other non-SI units

Quantity	Name of unit	Symbol for unit	Value in SI units
pressure	bar (*a*)	bar	1 bar = 0.1 MPa = 100 kPa = 10^5 Pa
	millimetre of mercury (*b*)	mmHg	1 mmHg ≈ 133.322 Pa
length	ångström (*c*)	Å	1 Å = 0.1 nm = 100 pm = 10^{-10} m
distance	nautical mile (*d*)	M	1 M = 1852 m
area	barn (*e*)	b	1 b = 100 $\text{fm}^2 = (10^{-12}\ \text{cm})^2 = 10^{-28}\ \text{m}^2$
speed	knot (*f*)	kn	1 kn = (1852/3600) m/s
logarithmic ratio quantities	neper (*g, i*)	Np	[see footnote (*j*) regarding the numerical value of the neper, the bel and the decibel]
	bel (*h, i*)	B	
	decibel (*h, i*)	dB	

(*a*) The bar and its symbol are included in Resolution 7 of the 9th CGPM (1948; CR, 70). Since 1982 one bar has been used as the standard pressure for tabulating all thermodynamic data. Prior to 1982 the standard pressure used to be the standard atmosphere, equal to 1.013 25 bar, or 101 325 Pa.

(*b*) The millimetre of mercury is a legal unit for the measurement of blood pressure in some countries.

(*c*) The ångström is widely used by x-ray crystallographers and structural chemists because all chemical bonds lie in the range 1 to 3 ångströms. However it has no official sanction from the CIPM or the CGPM.

(*d*) The nautical mile is a special unit employed for marine and aerial navigation to express distance. The conventional value given here was adopted by the First International Extraordinary Hydrographic Conference, Monaco 1929, under the name “International nautical mile”. As yet there is no internationally agreed symbol, but the symbols M, NM, Nm, and nmi are all used; in the table the symbol M is used. The unit was originally chosen, and continues to be used, because one nautical mile on the surface of the Earth subtends approximately one minute of angle at the centre of the Earth, which is convenient when latitude and longitude are measured in degrees and minutes of angle.

(*e*) The barn is a unit of area employed to express cross sections in nuclear physics.

(*f*) The knot is defined as one nautical mile per hour. There is no internationally agreed symbol, but the symbol kn is commonly used.

(*g*) The statement $L_A = n$ Np (where n is a number) is interpreted to mean that $\ln(A_2/A_1) = n$. Thus when $L_A = 1$ Np, $A_2/A_1 = \mathrm{e}$. The symbol A is used here to denote the amplitude of a sinusoidal signal, and L_A is then called the neperian logarithmic amplitude ratio, or the neperian amplitude level difference.

(*h*) The statement $L_X = m$ dB = $(m/10)$ B (where m is a number) is interpreted to mean that $\lg(X/X_0) = m/10$. Thus when $L_X = 1$ B, $X/X_0 = 10$, and when $L_X = 1$ dB, $X/X_0 = 10^{1/10}$. If X denotes a mean square signal or power-like quantity, L_X is called a power level referred to X_0.

(*i*) In using these units it is important that the nature of the quantity be specified, and that any reference value used be specified. These units are not SI units, but they have been accepted by the CIPM for use with the SI.

(*j*) The numerical values of the neper, bel, and decibel (and hence the relation of the bel and the decibel to the neper) are rarely required. They depend on the way in which the logarithmic quantities are defined.

Table 9 differs from Table 8 only in that the units in Table 9 are related to the older CGS (centimetre-gram-second) system of units, including the CGS electrical units. In the field of mechanics, the CGS system of units was built upon three quantities and their corresponding base units: the centimetre, the gram, and the second. The CGS electrical units were still derived from only these same three base units, using defining equations different from those used for the SI. Because this can be done in different ways, it led to the establishment of several different systems, namely the CGS-ESU (electrostatic), the CGS-EMU (electromagnetic), and the CGS-Gaussian unit systems. It has always been recognized that the CGS-Gaussian system, in particular, has advantages in certain areas of physics, particularly in classical and relativistic electrodynamics (9th CGPM, 1948, Resolution 6). Table 9 gives the relations between these CGS units and the SI, and lists those CGS units that were assigned special names. As for the units in Table 8, the SI prefixes are used with several of these units (e.g. millidyne, mdyn; milligauss, mG, etc.).

Table 9. Non-SI units associated with the CGS and the CGS-Gaussian system of units

Quantity	Name of unit	Symbol for unit	Value in SI units
energy	erg (*a*)	erg	$1\ \mathrm{erg} = 10^{-7}\ \mathrm{J}$
force	dyne (*a*)	dyn	$1\ \mathrm{dyn} = 10^{-5}\ \mathrm{N}$
dynamic viscosity	poise (*a*)	P	$1\ \mathrm{P} = 1\ \mathrm{dyn\ s\ cm^{-2}} = 0.1\ \mathrm{Pa\ s}$
kinematic viscosity	stokes	St	$1\ \mathrm{St} = 1\ \mathrm{cm^2\ s^{-1}} = 10^{-4}\ \mathrm{m^2\ s^{-1}}$
luminance	stilb (*a*)	sb	$1\ \mathrm{sb} = 1\ \mathrm{cd\ cm^{-2}} = 10^4\ \mathrm{cd\ m^{-2}}$
illuminance	phot	ph	$1\ \mathrm{ph} = 1\ \mathrm{cd\ sr\ cm^{-2}} = 10^4\ \mathrm{lx}$
acceleration	gal (*b*)	Gal	$1\ \mathrm{Gal} = 1\ \mathrm{cm\ s^{-2}} = 10^{-2}\ \mathrm{m\ s^{-2}}$
magnetic flux	maxwell (*c*)	Mx	$1\ \mathrm{Mx} = 1\ \mathrm{G\ cm^2} = 10^{-8}\ \mathrm{Wb}$
magnetic flux density	gauss (*c*)	G	$1\ \mathrm{G} = 1\ \mathrm{Mx\ cm^{-2}} = 10^{-4}\ \mathrm{T}$
magnetic field	œrsted (*c*)	Oe	$1\ \mathrm{Oe} \mathrel{\hat{=}} (10^3/4\pi)\ \mathrm{A\ m^{-1}}$

(*a*) This unit and its symbol were included in Resolution 7 of the 9th CGPM (1948; CR, 70).

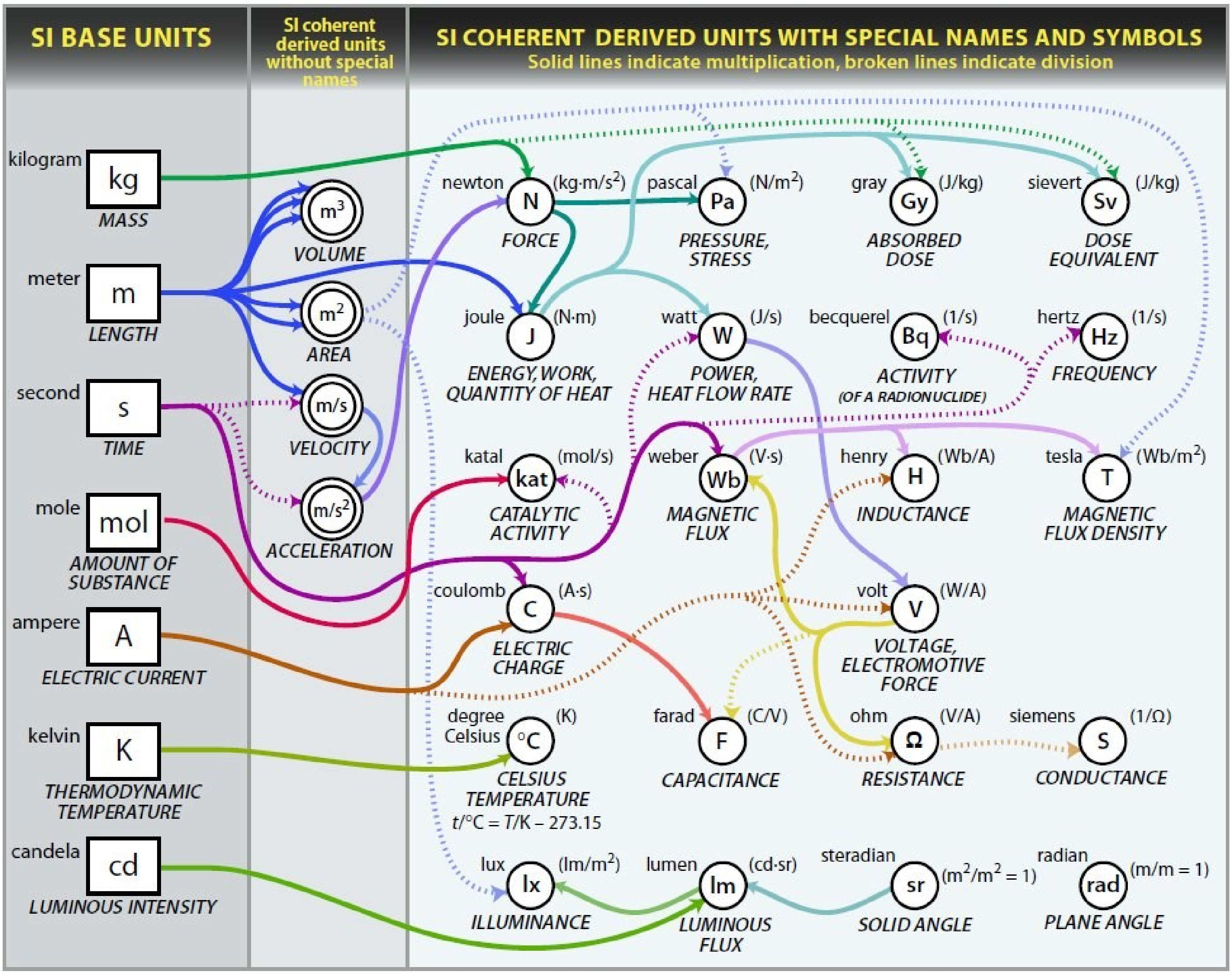
(*b*) The gal is a special unit of acceleration employed in geodesy and geophysics to express acceleration due to gravity.

(*c*) These units are part of the so-called “electromagnetic” three-dimensional CGS system based on unrationalized quantity equations, and must be compared with care to the corresponding unit of the International System which is based on rationalized equations involving four dimensions and four quantities for electromagnetic theory. The magnetic flux, Φ, and the magnetic flux density, B, are defined by similar equations in the CGS system and the SI, so that the corresponding units can be related as in the table. However, the unrationalized magnetic field, $H\text{(unrationalized)} = 4\pi \times H\text{(rationalized)}$. The equivalence symbol $\hat{=}$ is used to indicate that when $H\text{(unrationalized)} = 1\ \text{Oe}$, $H\text{(rationalized)} = (10^3/4\pi)\ \text{A m}^{-1}$.

4.2 Other non-SI units not recommended for use

There are many more non-SI units, which are too numerous to list here, which are either of historical interest, or are still used but only in specialized fields (for example, the barrel of oil) or in particular countries (the inch, foot, and yard). The CIPM can see no case for continuing to use these units in modern scientific and technical work. However, it is clearly a matter of importance to be able to recall the relation of these units to the corresponding SI units, and this will continue to be true for many years. The CIPM has therefore decided to compile a list of the conversion factors to the SI for such units and to make this available on the BIPM website at

www.bipm.org/en/si/si_brochure/chapter4/conversion_factors.html.


SI BASE UNITS
SI coherent derived units without special names
SI COHERENT DERIVED UNITS WITH SPECIAL NAMES AND SYMBOLS
Solid lines indicate multiplication, broken lines indicate division
kilogram kg MASS
meter m LENGTH
second s TIME
mole mol AMOUNT OF SUBSTANCE
ampere A ELECTRIC CURRENT
kelvin K THERMODYNAMIC TEMPERATURE
candela cd LUMINOUS INTENSITY
m^3 VOLUME
m^2 AREA
m/s VELOCITY
m/s^2 ACCELERATION
newton N ($kg \cdot m/s^2$) FORCE
pascal Pa (N/m^2) PRESSURE, STRESS
gray Gy (J/kg) ABSORBED DOSE
sievert Sv (J/kg) DOSE EQUIVALENT
joule J ($N \cdot m$) ENERGY, WORK, QUANTITY OF HEAT
watt W (J/s) POWER, HEAT FLOW RATE
becquerel Bq (1/s) ACTIVITY (OF A RADIONUCLIDE)
hertz Hz (1/s) FREQUENCY
katal kat (mol/s) CATALYTIC ACTIVITY
weber Wb ($V \cdot s$) MAGNETIC FLUX
henry H (Wb/A) INDUCTANCE
tesla T (Wb/m^2) MAGNETIC FLUX DENSITY
coulomb C ($A \cdot s$) ELECTRIC CHARGE
volt V (W/A) VOLTAGE, ELECTROMOTIVE FORCE
degree Celsius °C (K) CELSIUS TEMPERATURE
$t/°C = T/K - 273.15$
farad F (C/V) CAPACITANCE
ohm Ω (V/A) RESISTANCE
siemens S (1/Ω) CONDUCTANCE
lux lx (lm/m^2) ILLUMINANCE
lumen lm ($cd \cdot sr$) LUMINOUS FLUX
steradian sr ($m^2/m^2 = 1$) SOLID ANGLE
radian rad (m/m = 1) PLANE ANGLE