

Fundamental Physical Constants — Frequently used constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
speed of light in vacuum	c, c_0	299 792 458	m s^{-1}	(exact)
magnetic constant	μ_0	$4\pi \times 10^{-7}$ $= 12.566\,370\,614\dots \times 10^{-7}$	N A^{-2} N A^{-2}	(exact)
electric constant $1/\mu_0 c^2$	ϵ_0	$8.854\,187\,817\dots \times 10^{-12}$	F m^{-1}	(exact)
Newtonian constant of gravitation	G	$6.6742(10) \times 10^{-11}$	$\text{m}^3 \text{kg}^{-1} \text{s}^{-2}$	1.5×10^{-4}
Planck constant	h	$6.626\,0693(11) \times 10^{-34}$	J s	1.7×10^{-7}
$h/2\pi$	\hbar	$1.054\,571\,68(18) \times 10^{-34}$	J s	1.7×10^{-7}
elementary charge	e	$1.602\,176\,53(14) \times 10^{-19}$	C	8.5×10^{-8}
magnetic flux quantum $h/2e$	Φ_0	$2.067\,833\,72(18) \times 10^{-15}$	Wb	8.5×10^{-8}
conductance quantum $2e^2/h$	G_0	$7.748\,091\,733(26) \times 10^{-5}$	S	3.3×10^{-9}
electron mass	m_e	$9.109\,3826(16) \times 10^{-31}$	kg	1.7×10^{-7}
proton mass	m_p	$1.672\,621\,71(29) \times 10^{-27}$	kg	1.7×10^{-7}
proton-electron mass ratio	m_p/m_e	1836.152 672 61(85)		4.6×10^{-10}
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,568(24) \times 10^{-3}$		3.3×10^{-9}
inverse fine-structure constant	α^{-1}	137.035 999 11(46)		3.3×10^{-9}
Rydberg constant $\alpha^2 m_e c/2h$	R_∞	10 973 731.568 525(73)	m^{-1}	6.6×10^{-12}
Avogadro constant	N_A, L	$6.022\,1415(10) \times 10^{23}$	mol^{-1}	1.7×10^{-7}
Faraday constant $N_A e$	F	96 485.3383(83)	C mol^{-1}	8.6×10^{-8}
molar gas constant	R	8.314 472(15)	$\text{J mol}^{-1} \text{K}^{-1}$	1.7×10^{-6}
Boltzmann constant R/N_A	k	$1.380\,6505(24) \times 10^{-23}$	J K^{-1}	1.8×10^{-6}
Stefan-Boltzmann constant $(\pi^2/60)k^4/\hbar^3 c^2$	σ	$5.670\,400(40) \times 10^{-8}$	$\text{W m}^{-2} \text{K}^{-4}$	7.0×10^{-6}
Non-SI units accepted for use with the SI				
electron volt: $(e/C) \text{ J}$	eV	$1.602\,176\,53(14) \times 10^{-19}$	J	8.5×10^{-8}
(unified) atomic mass unit $1 \text{ u} = m_u = \frac{1}{12} m(^{12}\text{C})$ $= 10^{-3} \text{ kg mol}^{-1}/N_A$	u	$1.660\,538\,86(28) \times 10^{-27}$	kg	1.7×10^{-7}

Fundamental Physical Constants — Non-SI units

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
electron volt: (e/C) J	eV	$1.602\,176\,53(14) \times 10^{-19}$	J	8.5×10^{-8}
(unified) atomic mass unit: 1 u = $m_u = \frac{1}{12}m(^{12}\text{C})$ = $10^{-3} \text{ kg mol}^{-1}/N_A$	u	$1.660\,538\,86(28) \times 10^{-27}$	kg	1.7×10^{-7}
Natural units (n.u.)				
n.u. of velocity: speed of light in vacuum	c, c_0	299 792 458	m s^{-1}	(exact)
n.u. of action: reduced Planck constant ($\hbar/2\pi$)	\hbar	$1.054\,571\,68(18) \times 10^{-34}$	J s	1.7×10^{-7}
in eV s		$6.582\,119\,15(56) \times 10^{-16}$	eV s	8.5×10^{-8}
in MeV fm	$\hbar c$	197.326 968(17)	MeV fm	8.5×10^{-8}
n.u. of mass: electron mass	m_e	$9.109\,3826(16) \times 10^{-31}$	kg	1.7×10^{-7}
n.u. of energy in MeV	$m_e c^2$	$8.187\,1047(14) \times 10^{-14}$ 0.510 998 918(44)	J MeV	1.7×10^{-7} 8.6×10^{-8}
n.u. of momentum in MeV/c	$m_e c$	$2.730\,924\,19(47) \times 10^{-22}$ 0.510 998 918(44)	kg m s^{-1} MeV/c	1.7×10^{-7} 8.6×10^{-8}
n.u. of length ($\hbar/m_e c$)	λ_C	$386.159\,2678(26) \times 10^{-15}$	m	6.7×10^{-9}
n.u. of time	$\hbar/m_e c^2$	$1.288\,088\,6677(86) \times 10^{-21}$	s	6.7×10^{-9}
Atomic units (a.u.)				
a.u. of charge: elementary charge	e	$1.602\,176\,53(14) \times 10^{-19}$	C	8.5×10^{-8}
a.u. of mass: electron mass	m_e	$9.109\,3826(16) \times 10^{-31}$	kg	1.7×10^{-7}
a.u. of action: reduced Planck constant ($\hbar/2\pi$)	\hbar	$1.054\,571\,68(18) \times 10^{-34}$	J s	1.7×10^{-7}
a.u. of length: Bohr radius (bohr) ($\alpha/4\pi R_\infty$)	a_0	$0.529\,177\,2108(18) \times 10^{-10}$	m	3.3×10^{-9}
a.u. of energy: Hartree energy (hartree) ($e^2/4\pi\epsilon_0 a_0 = 2R_\infty hc = \alpha^2 m_e c^2$)	E_h	$4.359\,744\,17(75) \times 10^{-18}$	J	1.7×10^{-7}

VECTOR IDENTITIES⁴

Notation: f, g , are scalars; \mathbf{A}, \mathbf{B} , etc., are vectors; T is a tensor; I is the unit dyad.

$$(1) \mathbf{A} \cdot \mathbf{B} \times \mathbf{C} = \mathbf{A} \times \mathbf{B} \cdot \mathbf{C} = \mathbf{B} \cdot \mathbf{C} \times \mathbf{A} = \mathbf{B} \times \mathbf{C} \cdot \mathbf{A} = \mathbf{C} \cdot \mathbf{A} \times \mathbf{B} = \mathbf{C} \times \mathbf{A} \cdot \mathbf{B}$$

$$(2) \mathbf{A} \times (\mathbf{B} \times \mathbf{C}) = (\mathbf{C} \times \mathbf{B}) \times \mathbf{A} = (\mathbf{A} \cdot \mathbf{C})\mathbf{B} - (\mathbf{A} \cdot \mathbf{B})\mathbf{C}$$

$$(3) \mathbf{A} \times (\mathbf{B} \times \mathbf{C}) + \mathbf{B} \times (\mathbf{C} \times \mathbf{A}) + \mathbf{C} \times (\mathbf{A} \times \mathbf{B}) = 0$$

$$(4) (\mathbf{A} \times \mathbf{B}) \cdot (\mathbf{C} \times \mathbf{D}) = (\mathbf{A} \cdot \mathbf{C})(\mathbf{B} \cdot \mathbf{D}) - (\mathbf{A} \cdot \mathbf{D})(\mathbf{B} \cdot \mathbf{C})$$

$$(5) (\mathbf{A} \times \mathbf{B}) \times (\mathbf{C} \times \mathbf{D}) = (\mathbf{A} \times \mathbf{B} \cdot \mathbf{D})\mathbf{C} - (\mathbf{A} \times \mathbf{B} \cdot \mathbf{C})\mathbf{D}$$

$$(6) \nabla(fg) = \nabla(gf) = f\nabla g + g\nabla f$$

$$(7) \nabla \cdot (f\mathbf{A}) = f\nabla \cdot \mathbf{A} + \mathbf{A} \cdot \nabla f$$

$$(8) \nabla \times (f\mathbf{A}) = f\nabla \times \mathbf{A} + \nabla f \times \mathbf{A}$$

$$(9) \nabla \cdot (\mathbf{A} \times \mathbf{B}) = \mathbf{B} \cdot \nabla \times \mathbf{A} - \mathbf{A} \cdot \nabla \times \mathbf{B}$$

$$(10) \nabla \times (\mathbf{A} \times \mathbf{B}) = \mathbf{A}(\nabla \cdot \mathbf{B}) - \mathbf{B}(\nabla \cdot \mathbf{A}) + (\mathbf{B} \cdot \nabla)\mathbf{A} - (\mathbf{A} \cdot \nabla)\mathbf{B}$$

$$(11) \mathbf{A} \times (\nabla \times \mathbf{B}) = (\nabla \mathbf{B}) \cdot \mathbf{A} - (\mathbf{A} \cdot \nabla)\mathbf{B}$$

$$(12) \nabla(\mathbf{A} \cdot \mathbf{B}) = \mathbf{A} \times (\nabla \times \mathbf{B}) + \mathbf{B} \times (\nabla \times \mathbf{A}) + (\mathbf{A} \cdot \nabla)\mathbf{B} + (\mathbf{B} \cdot \nabla)\mathbf{A}$$

$$(13) \nabla^2 f = \nabla \cdot \nabla f$$

$$(14) \nabla^2 \mathbf{A} = \nabla(\nabla \cdot \mathbf{A}) - \nabla \times \nabla \times \mathbf{A}$$

$$(15) \nabla \times \nabla f = 0$$

$$(16) \nabla \cdot \nabla \times \mathbf{A} = 0$$

If $\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3$ are orthonormal unit vectors, a second-order tensor T can be written in the dyadic form

$$(17) T = \sum_{i,j} T_{ij} \mathbf{e}_i \mathbf{e}_j$$

In cartesian coordinates the divergence of a tensor is a vector with components

$$(18) (\nabla \cdot T)_i = \sum_j (\partial T_{ji} / \partial x_j)$$

[This definition is required for consistency with Eq. (29)]. In general

$$(19) \nabla \cdot (\mathbf{A}\mathbf{B}) = (\nabla \cdot \mathbf{A})\mathbf{B} + (\mathbf{A} \cdot \nabla)\mathbf{B}$$

$$(20) \nabla \cdot (fT) = \nabla f \cdot T + f\nabla \cdot T$$

The ∇ -operator

In cartesian coordinates (x, y, z) holds:

$$\begin{aligned}\vec{\nabla} &= \frac{\partial}{\partial x}\vec{e}_x + \frac{\partial}{\partial y}\vec{e}_y + \frac{\partial}{\partial z}\vec{e}_z, \quad \text{grad}f = \vec{\nabla}f = \frac{\partial f}{\partial x}\vec{e}_x + \frac{\partial f}{\partial y}\vec{e}_y + \frac{\partial f}{\partial z}\vec{e}_z \\ \text{div} \vec{a} &= \vec{\nabla} \cdot \vec{a} = \frac{\partial a_x}{\partial x} + \frac{\partial a_y}{\partial y} + \frac{\partial a_z}{\partial z}, \quad \nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} + \frac{\partial^2 f}{\partial z^2} \\ \text{rot} \vec{a} &= \vec{\nabla} \times \vec{a} = \left(\frac{\partial a_z}{\partial y} - \frac{\partial a_y}{\partial z} \right) \vec{e}_x + \left(\frac{\partial a_x}{\partial z} - \frac{\partial a_z}{\partial x} \right) \vec{e}_y + \left(\frac{\partial a_y}{\partial x} - \frac{\partial a_x}{\partial y} \right) \vec{e}_z\end{aligned}$$

In cylinder coordinates (r, φ, z) holds:

$$\begin{aligned}\vec{\nabla} &= \frac{\partial}{\partial r}\vec{e}_r + \frac{1}{r}\frac{\partial}{\partial \varphi}\vec{e}_\varphi + \frac{\partial}{\partial z}\vec{e}_z, \quad \text{grad}f = \frac{\partial f}{\partial r}\vec{e}_r + \frac{1}{r}\frac{\partial f}{\partial \varphi}\vec{e}_\varphi + \frac{\partial f}{\partial z}\vec{e}_z \\ \text{div} \vec{a} &= \frac{\partial a_r}{\partial r} + \frac{a_r}{r} + \frac{1}{r}\frac{\partial a_\varphi}{\partial \varphi} + \frac{\partial a_z}{\partial z}, \quad \nabla^2 f = \frac{\partial^2 f}{\partial r^2} + \frac{1}{r}\frac{\partial f}{\partial r} + \frac{1}{r^2}\frac{\partial^2 f}{\partial \varphi^2} + \frac{\partial^2 f}{\partial z^2} \\ \text{rot} \vec{a} &= \left(\frac{1}{r}\frac{\partial a_z}{\partial \varphi} - \frac{\partial a_\varphi}{\partial z} \right) \vec{e}_r + \left(\frac{\partial a_r}{\partial z} - \frac{\partial a_z}{\partial r} \right) \vec{e}_\varphi + \left(\frac{\partial a_\varphi}{\partial r} + \frac{a_\varphi}{r} - \frac{1}{r}\frac{\partial a_r}{\partial \varphi} \right) \vec{e}_z\end{aligned}$$

In spherical coordinates (r, θ, φ) holds:

$$\begin{aligned}\vec{\nabla} &= \frac{\partial}{\partial r}\vec{e}_r + \frac{1}{r}\frac{\partial}{\partial \theta}\vec{e}_\theta + \frac{1}{r\sin\theta}\frac{\partial}{\partial \varphi}\vec{e}_\varphi \\ \text{grad}f &= \frac{\partial f}{\partial r}\vec{e}_r + \frac{1}{r}\frac{\partial f}{\partial \theta}\vec{e}_\theta + \frac{1}{r\sin\theta}\frac{\partial f}{\partial \varphi}\vec{e}_\varphi \\ \text{div} \vec{a} &= \frac{\partial a_r}{\partial r} + \frac{2a_r}{r} + \frac{1}{r}\frac{\partial a_\theta}{\partial \theta} + \frac{a_\theta}{r\tan\theta} + \frac{1}{r\sin\theta}\frac{\partial a_\varphi}{\partial \varphi} \\ \text{rot} \vec{a} &= \left(\frac{1}{r}\frac{\partial a_\varphi}{\partial \theta} + \frac{a_\theta}{r\tan\theta} - \frac{1}{r\sin\theta}\frac{\partial a_\theta}{\partial \varphi} \right) \vec{e}_r + \left(\frac{1}{r\sin\theta}\frac{\partial a_r}{\partial \varphi} - \frac{\partial a_\varphi}{\partial r} - \frac{a_\varphi}{r} \right) \vec{e}_\theta + \\ &\quad \left(\frac{\partial a_\theta}{\partial r} + \frac{a_\theta}{r} - \frac{1}{r}\frac{\partial a_r}{\partial \theta} \right) \vec{e}_\varphi \\ \nabla^2 f &= \frac{\partial^2 f}{\partial r^2} + \frac{2}{r}\frac{\partial f}{\partial r} + \frac{1}{r^2}\frac{\partial^2 f}{\partial \theta^2} + \frac{1}{r^2\tan\theta}\frac{\partial f}{\partial \theta} + \frac{1}{r^2\sin^2\theta}\frac{\partial^2 f}{\partial \varphi^2}\end{aligned}$$

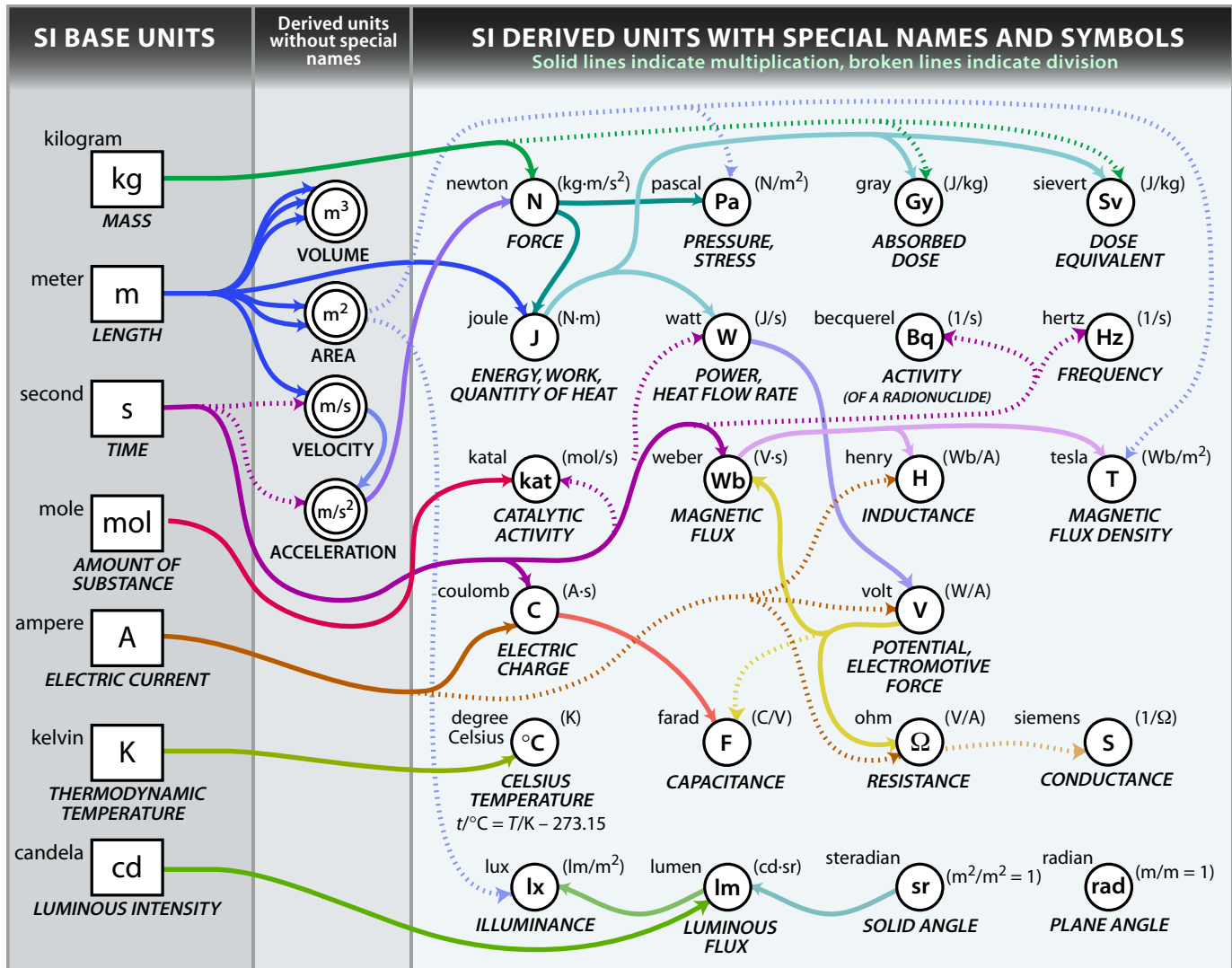
General orthonormal curvilinear coordinates (u, v, w) can be obtained from cartesian coordinates by the transformation $\vec{x} = \vec{x}(u, v, w)$. The unit vectors are then given by:

$$\vec{e}_u = \frac{1}{h_1}\frac{\partial \vec{x}}{\partial u}, \quad \vec{e}_v = \frac{1}{h_2}\frac{\partial \vec{x}}{\partial v}, \quad \vec{e}_w = \frac{1}{h_3}\frac{\partial \vec{x}}{\partial w}$$

where the factors h_i set the norm to 1. Then holds:

$$\begin{aligned}\text{grad}f &= \frac{1}{h_1}\frac{\partial f}{\partial u}\vec{e}_u + \frac{1}{h_2}\frac{\partial f}{\partial v}\vec{e}_v + \frac{1}{h_3}\frac{\partial f}{\partial w}\vec{e}_w \\ \text{div} \vec{a} &= \frac{1}{h_1 h_2 h_3} \left(\frac{\partial}{\partial u}(h_2 h_3 a_u) + \frac{\partial}{\partial v}(h_3 h_1 a_v) + \frac{\partial}{\partial w}(h_1 h_2 a_w) \right) \\ \text{rot} \vec{a} &= \frac{1}{h_2 h_3} \left(\frac{\partial(h_3 a_w)}{\partial v} - \frac{\partial(h_2 a_v)}{\partial w} \right) \vec{e}_u + \frac{1}{h_3 h_1} \left(\frac{\partial(h_1 a_u)}{\partial w} - \frac{\partial(h_3 a_w)}{\partial u} \right) \vec{e}_v + \\ &\quad \frac{1}{h_1 h_2} \left(\frac{\partial(h_2 a_v)}{\partial u} - \frac{\partial(h_1 a_u)}{\partial v} \right) \vec{e}_w \\ \nabla^2 f &= \frac{1}{h_1 h_2 h_3} \left[\frac{\partial}{\partial u} \left(\frac{h_2 h_3}{h_1} \frac{\partial f}{\partial u} \right) + \frac{\partial}{\partial v} \left(\frac{h_3 h_1}{h_2} \frac{\partial f}{\partial v} \right) + \frac{\partial}{\partial w} \left(\frac{h_1 h_2}{h_3} \frac{\partial f}{\partial w} \right) \right]\end{aligned}$$

Relationships of the SI derived units with special names and symbols and the SI base units



The diagram above shows graphically how the 22 SI derived units with special names and symbols are related to the seven SI base units. In the first column, the symbols of the SI base units are shown in rectangles, with the name of the unit shown toward the upper left of the rectangle and the name of the associated base quantity shown in italic type below the rectangle. In the third column the symbols of the derived units with special names are shown in solid circles, with the name of the unit shown toward the upper left of the circle, the name of the associated derived quantity shown in italic type below the circle, and an expression for the derived unit in terms of other units shown toward the upper right in parenthesis. In the second column are shown those derived units without special names [the cubic meter (m^3) excepted] that are used in the derivation of the derived units with special names. In the diagram, the derivation of each derived unit is indicated by arrows that bring in units in the numerator (solid lines) and units in the denominator (broken lines), as appropriate.

Two SI derived units with special names and symbols, the radian, symbol rad, and the steradian, symbol sr (bottom of the third column of the diagram), are shown without any connections to SI base units – either direct or through other SI derived units. The reason is that in the SI, the quantities plane angle and solid angle are defined in such a way that their dimension is one – they are so-called dimensionless quantities. This means that the coherent SI derived unit for each of these quantities is the number one, symbol 1. That is, because plane angle is expressed as the ratio of two lengths, and solid angle as the ratio of an area and the square of a length, the SI derived unit for plane angle is $m/m = 1$, and the SI derived unit for solid angle is $m^2/m^2 = 1$. To aid understanding, the special name radian with symbol rad is given to the number 1 for use in expressing values of plane angle; and the special name steradian with symbol sr is given to the number 1 for use in expressing values of solid angle. However, one has the option of using or not using these names and symbols in expressions for other SI derived units, as is convenient.

The unit “degree Celsius,” which is equal to the unit “kelvin,” is used to express Celsius temperature t . In this case, “degree Celsius” is a special name used in place of “kelvin.” This equality is indicated in the diagram by the symbol K in parenthesis toward the upper right of the $^{\circ}\text{C}$ circle. The equation below “CELSIUS TEMPERATURE” relates Celsius temperature t to thermodynamic temperature T . An interval or difference of Celsius temperature can, however, be expressed in kelvins as well as in degrees Celsius.

2 SI units

2.1 SI base units

Formal definitions of all SI base units are approved by the CGPM. The first such definition was approved in 1889 and the most recent in 1983. These definitions are modified from time to time as techniques of measurement evolve and allow more accurate realizations of the base units.

2.1.1 Definitions

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

2.1.1.1 Unit of length (metre)

The 1889 definition of the metre, based upon the international prototype of platinum-iridium, was replaced by the 11th CGPM (1960) using a definition based upon a wavelength of krypton 86 radiation. This definition was adopted in order to improve the accuracy with which the metre may be realized. In turn, this was replaced in 1983 by the 17th CGPM (Resolution 1; CR, 97 and *Metrologia*, 1984, **20**, 25):

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.

Note that the effect of this definition is to fix the speed of light at exactly $299\,792\,458\text{ m}\cdot\text{s}^{-1}$. 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, made of platinum-iridium, is kept at the BIPM under 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 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 page 118.

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 based on astronomical theories. However, measurement showed that irregularities in the rotation of the Earth could not be taken into account by the theory and have the effect that this definition does not allow the required accuracy to be achieved. In order to define the unit of time more precisely, the 11th CGPM (1960; CR, 86) adopted a definition given by the International Astronomical Union which was based on the tropical year. Experimental work, however, had already shown that an atomic standard of time interval, based on a transition between two energy levels of an atom or a molecule, could be realized and reproduced much more precisely. Considering that a very precise definition of the unit of time is indispensable for the International System, the 13th CGPM (1967-1968, 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.

At its 1997 meeting, the CIPM affirmed that:

This definition refers to a caesium atom in its ground state at a temperature of 0 K.

2.1.1.4 Unit of electric current (ampere)

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

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). Note that the effect of this definition is to fix the permeability of vacuum at exactly $4\pi \times 10^{-7} \text{ H} \cdot \text{m}^{-1}$.

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 (1967-1968, 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 (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.

Because of the way 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 $T_0 = 273.15 \text{ K}$, the ice point. This temperature difference is called the Celsius temperature, symbol t , and 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, 1967-1968, Resolution 3, mentioned above). The numerical value of a Celsius temperature t expressed in degrees Celsius is given by

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

The kelvin and the degree Celsius are also the 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 isotopes in the mass spectrometer and attributed the value 16 to one of the isotopes of oxygen, chemists attributed that 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 “atomic weight”, correctly the relative atomic mass, of the isotope of carbon with mass number 12 (carbon 12, ^{12}C). The unified scale thus obtained gives values of relative atomic mass.

It remained to define the unit of amount of substance by fixing the corresponding mass of carbon 12; by international agreement this mass was fixed at 0.012 kg, and the unit of the quantity “amount of substance” was given the name *mole* (symbol mol).

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.**

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.

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 Planckian 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 the 1946 definition.

In 1979, because of the experimental 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.

2.1.2 Symbols for 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 (10th CGPM (1954, Resolution 6; CR, 80); 11th CGPM (1960, Resolution 12; CR, 87); 13th CGPM (1967-1968, 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
length	metre	m
mass	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

2.2 SI derived units

Derived units are units which may be expressed in terms of base units by means of the mathematical symbols of multiplication and division. Certain derived units have been given special names and symbols, and these special names and symbols may themselves be used in combination with those for base and other derived units to express the units of other quantities.

2.2.1 Units expressed in terms of base units

Table 2 lists some examples of derived units expressed directly in terms of base units. The derived units are obtained by multiplication and division of base units.

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

Derived quantity	SI derived unit	
	Name	Symbol
area	square metre	m ²
volume	cubic metre	m ³
speed, velocity	metre per second	m/s
acceleration	metre per second squared	m/s ²
wavenumber	reciprocal metre	m ⁻¹
density, mass density	kilogram per cubic metre	kg/m ³
specific volume	cubic metre per kilogram	m ³ /kg
current density	ampere per square metre	A/m ²
magnetic field strength	ampere per metre	A/m
concentration (of amount of substance)	mole per cubic metre	mol/m ³
luminance	candela per square metre	cd/m ²
refractive index	(the number) one	1 ^(a)

(a) The symbol “1” is generally omitted in combination with a numerical value.

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

For convenience, certain derived units, which are listed in Table 3, have been given special names and symbols. These names and symbols may themselves be used to express other derived units: Table 4 shows some examples. The special names and symbols are a compact form for the expression of units which are used frequently.

Among these names and symbols, the last three entries in Table 3 are of particular note since they were accepted by the 15th CGPM (1975, Resolutions 8 and 9; CR, 105 and *Metrologia*, 1975, **11**, 180) and the 16th CGPM (1979, Resolution 5; CR, 100 and *Metrologia*, 1980, **16**, 56) specifically with a view to safeguarding human health.

In 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 m⁰, kg⁰ ..., which are all equal to 1, are not shown explicitly.

Table 3. SI derived units with special names and symbols

Derived quantity	Name	Symbol	SI derived unit	
			Expressed in terms of other SI units	Expressed in terms of SI base units
plane angle	radian ^(a)	rad		$m \cdot m^{-1} = 1^{(b)}$
solid angle	steradian ^(a)	sr ^(c)		$m^2 \cdot m^{-2} = 1^{(b)}$
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 · 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 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 · 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	degree Celsius ^(d)	°C		K
luminous flux	lumen	lm	cd · sr ^(c)	$m^2 \cdot m^{-2} \cdot cd = cd$
illuminance	lux	lx	lm/m ²	$m^2 \cdot m^{-4} \cdot cd = m^{-2} \cdot cd$
activity (referred to 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, organ equivalent dose	sievert	Sv	J/kg	$m^2 \cdot s^{-2}$

(a) The radian and steradian may be used with advantage in expressions for derived units to distinguish between quantities of different nature but the same dimension. Some examples of their use in forming derived units are given in Table 4.

(b) In practice, the symbols rad and sr are used where appropriate, but the derived unit “1” is generally omitted in combination with a numerical value.

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

(d) This unit may be used in combination with SI prefixes, e.g. millidegree Celsius, m°C.

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

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

A single SI unit may correspond to several different quantities, as noted in paragraph 1.2 (p. 92). In the above table, which is not exhaustive, there are several examples. Thus the joule per kelvin (J/K) is the SI unit for the quantity heat capacity as well as for the quantity entropy; also the ampere (A) is the SI unit for the base quantity electric current as well as for the derived quantity magnetomotive force. It is therefore important not to use the unit alone to specify the quantity. This rule applies not only to scientific and technical texts but also, for example, to measuring instruments (i.e. an instrument should indicate both the unit and the quantity measured).

A derived unit can often be expressed in different ways by combining the names of base units with special names for derived units. This, however, is an algebraic freedom to be governed by common-sense physical considerations. Joule, for example, may formally be written newton metre, or even kilogram metre squared per second squared, but 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, in order to facilitate the distinction between different quantities having the same dimension. For example, the SI unit of frequency is designated the hertz, rather than the reciprocal second, and the SI unit of angular velocity is designated the radian per second rather than the reciprocal second (in this case retaining the word radian emphasizes that angular velocity is equal to 2π times the rotational frequency). Similarly the SI unit of moment of force is designated the newton metre rather than the joule.

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 the gray and 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 which might arise from mistakes involving the units reciprocal second and the joule per kilogram.

The CIPM, recognizing the particular importance of the health-related units, agreed a detailed text on the sievert for the 5th edition of this brochure: see p. 127, Recommendation 1 (CI-1984) adopted by the CIPM (PV, 1984, 52, 31 and *Metrologia*, 1985, 21, 90).

2.2.3 Units for dimensionless quantities, quantities of dimension one

Certain quantities are defined as the ratios of two quantities of the same kind, and thus have a dimension which may be expressed by the number one. The unit of such quantities is necessarily a derived unit coherent with the other units of the SI and, since it is formed as the ratio of two identical SI units, the unit also may be expressed by the number one. Thus the SI unit of all quantities having the dimensional product one is the number one. Examples of such quantities are refractive index, relative permeability, and friction factor. Other quantities having the unit 1 include “characteristic numbers” like the Prandtl number $\eta c_p/\lambda$ and numbers which represent a count, such as a number of molecules, degeneracy (number of energy levels) and partition function in statistical thermodynamics. All of these quantities are described as being dimensionless, or of dimension one, and have the coherent SI unit 1. Their values are simply expressed as numbers and, in general, the unit 1 is not explicitly shown. In a few cases, however, a special name is given to this unit, mainly to avoid confusion between some compound derived units. This is the case for the radian, steradian and neper.

3 Decimal multiples and submultiples of SI units

3.1 SI prefixes

The 11th CGPM (1960, Resolution 12; CR, 87) adopted a series of prefixes 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 prefixes 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).

Table 5. SI prefixes

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

3.2 The kilogram

Among the base units of the International System, the unit of mass is the only one whose name, for historical reasons, contains 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),

Example: 10^{-6} kg = 1 mg (1 milligram)
but not 1 μ kg (1 microkilo gram).

4 Units outside the SI

SI units are recommended for use throughout science, technology and commerce. They are agreed internationally by the CGPM, and provide the reference in terms of which all other units are now defined. The SI base units and SI 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 in quantity equations.

Nonetheless it is recognized that some non-SI units still appear widely in the scientific, technical and commercial literature, and some will probably continue to be used for many years. Other non-SI units, such as the units of time, are so widely used in everyday life, and are so deeply embedded in the history and culture of the human race, that they will continue to be used for the foreseeable future. For these reasons some of the more important non-SI units are listed in the tables below.

The inclusion of tables of non-SI units in this text does not imply that the use of non-SI units is to be encouraged. With a few exceptions discussed below, SI units are always to be preferred to non-SI units. It is desirable to avoid combining non-SI units with units of the SI; in particular the combination of such units with SI units to form compound units should be restricted to special cases so as to retain the advantage of coherence conferred by the use of SI units.

4.1 Units used with the SI

The CIPM (1969), recognizing that users would wish to employ the SI with units which are not part of it but are important and widely used, listed three categories of non-SI units: units to be maintained; to be tolerated temporarily; and to be avoided. In reviewing this categorization the CIPM (1996) agreed a new classification of non-SI units: units accepted for use with the SI, Table 6; units accepted for use with the SI whose values are obtained experimentally, Table 7; and other units currently accepted for use with the SI to satisfy the needs of special interests, Table 8.

Table 6 lists non-SI units which are accepted for use with the SI. It includes units which are in continuous everyday use, in particular the traditional units of time and of angle, together with a few other units which have assumed increasing technical importance.

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

Name	Symbol	Value in SI units
minute	min	1 min = 60 s
hour ^(a)	h	1 h = 60 min = 3600 s
day	d	1 d = 24 h = 86 400 s
degree ^(b)	°	1° = ($\pi/180$) rad
minute	'	1' = (1/60)° = ($\pi/10\ 800$) rad
second	"	1" = (1/60)' = ($\pi/648\ 000$) rad
litre ^(c)	l, L	1 l = 1 dm ³ = 10 ⁻³ m ³
tonne ^(d, e)	t	1 t = 10 ³ kg
neper ^(f, h)	Np	1 Np = 1
bel ^(g, h)	B	1 B = (1/2) ln 10 (Np) ⁽ⁱ⁾

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

(b) ISO 31 recommends that the degree be subdivided decimally rather than using the minute and second.

(c) This unit and the symbol l were adopted by CIPM in 1879 (PV, 1879, 41). The alternative symbol, 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 and the number 1. The present definition of the litre is given in Resolution 6 of the 12th CGPM (1964; CR, 93).

(d) This unit and its symbol were adopted by the CIPM in 1879 (PV, 1879, 41).

(e) In some English-speaking countries this unit is called "metric ton".

(f) The neper is used to express values of such logarithmic quantities as field level, power level, sound pressure level, and logarithmic decrement. Natural logarithms are used to obtain the numerical values of quantities expressed in nepers. The neper is coherent with the SI, but not yet adopted by the CGPM as an SI unit. For further information see International Standard ISO 31.

(g) The bel is used to express values of such logarithmic quantities as field level, power level, sound pressure level, and attenuation. Logarithms to base ten are used to obtain the numerical values of quantities expressed in bels. The submultiple decibel, dB, is commonly used. For further information see International Standard ISO 31.

(h) In using these units it is particularly important that the quantity be specified. The unit must not be used to imply the quantity.

(i) Np is enclosed in parentheses because, although the neper is coherent with the SI, it has not yet been adopted by the CGPM.

Table 7 lists three non-SI units which are also accepted for use with the SI, whose values expressed in SI units must be obtained by experiment and are therefore not known exactly. Their values are given with their combined standard uncertainties (coverage factor $k = 1$), which apply to the last two digits, shown in parentheses. These units are in common use in certain specialized fields.

Table 7. Non-SI units accepted for use with the International System, whose values in SI units are obtained experimentally

Name	Symbol	Definition	Value in SI units
electronvolt ^(a)	eV	^(b)	1 eV = 1.602 177 33 (49) × 10 ⁻¹⁹ J
unified atomic mass unit ^(a)	u	^(c)	1 u = 1.660 540 2 (10) × 10 ⁻²⁷ kg
astronomical unit ^(a)	ua	^(d)	1 ua = 1.495 978 706 91 (30) × 10 ¹¹ m

(a) For the electronvolt and the unified atomic mass unit, values are quoted from *CODATA Bulletin*, 1986, No. 63.

The value given for the astronomical unit is quoted from the IERS Conventions (1996), D.D. McCarthy ed., *IERS Technical Note 21*, Observatoire de Paris, July 1996.

(b) The electronvolt is the kinetic energy acquired by an electron in passing through a potential difference of 1 V in vacuum.

(c) The unified atomic mass unit is equal to 1/12 of the mass of an unbound atom of the nuclide ¹²C, at rest, and in its ground state. In the field of biochemistry, the unified atomic mass unit is also called the dalton, symbol Da.

(d) The astronomical unit is a unit of length approximately equal to the mean Earth-Sun distance. Its value is such that, when used to describe the motion of bodies in the Solar System, the heliocentric gravitational constant is (0.017 202 098 95)² ua³ · d⁻².

Table 8 lists some other non-SI units which are currently accepted for use with the SI to satisfy the needs of commercial, legal and specialized scientific interests. These units should be defined in relation to the SI in every document in which they are used. Their use is not encouraged.

Table 8. Other non-SI units currently accepted for use with the International System

Name	Symbol	Value in SI units
nautical mile ^(a)		1 nautical mile = 1852 m
knot		1 nautical mile per hour = (1852/3600) m/s
are ^(b)	a	1 a = 1 dam ² = 10 ² m ²
hectare ^(b)	ha	1 ha = 1 hm ² = 10 ⁴ m ²
bar ^(c)	bar	1 bar = 0.1 MPa = 100 kPa = 1000 hPa = 10 ⁵ Pa
ångström	Å	1 Å = 0.1 nm = 10 ⁻¹⁰ m
barn ^(d)	b	1 b = 100 fm ² = 10 ⁻²⁸ m ²

(a) The nautical mile is a special unit employed for marine and aerial navigation to express distance. The conventional value given above 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. This unit was originally chosen because one nautical mile on the surface of the Earth subtends approximately one minute of angle at the centre.

(b) The units are are and hectare and their symbols were adopted by the CIPM in 1879 (PV, 1879, 41) and are used to express areas of land.

(c) The bar and its symbol are included in Resolution 7 of the 9th CGPM (1948; CR, 70).

(d) The barn is a special unit employed in nuclear physics to express effective cross-sections.

4.2 Other non-SI units

Certain other non-SI units are still occasionally used. Some are important for the interpretation of older scientific texts. These are listed in Tables 9 and 10, but their use is not encouraged.

Table 9 deals with the relationship between CGS units and the SI, and lists those CGS units that were assigned special names. In the field of mechanics, the CGS system of units was built upon three quantities and the corresponding base units: the centimetre, the gram and the second. In the field of electricity and magnetism, units were expressed in terms of these three base units. Because this can be done in different ways, it led to the establishment of several different systems, for example the CGS Electrostatic System, the CGS Electromagnetic System and the CGS Gaussian System. In these three last-mentioned systems, the system of quantities and the corresponding system of equations differ from those used with SI units.

Table 9. Derived CGS units with special names

Name	Symbol	Value in SI units
erg ^(a)	erg	1 erg = 10 ⁻⁷ J
dyne ^(a)	dyn	1 dyn = 10 ⁻⁵ N
poise ^(a)	P	1 P = 1 dyn · s/cm ² = 0.1 Pa · s
stokes	St	1 St = 1 cm ² /s = 10 ⁻⁴ m ² /s
gauss ^(b)	G	1 G ^ 10 ⁻⁴ T
oersted ^(b)	Oe	1 Oe ^ (1000/4π) A/m
maxwell ^(b)	Mx	1 Mx ^ 10 ⁻⁸ Wb
stilb ^(a)	sb	1 sb = 1 cd/cm ² = 10 ⁴ cd/m ²
phot	ph	1 ph = 10 ⁴ lx
gal ^(c)	Gal	1 Gal = 1 cm/s ² = 10 ⁻² m/s ²

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

(b) This unit is part of the so-called “electromagnetic” three-dimensional CGS system and cannot strictly be compared with the corresponding unit of the International System, which has four dimensions when only mechanical and electric quantities are considered. For this reason, this unit is linked to the SI unit using the mathematical symbol for “corresponds to” (^).

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

Table 10 lists units which are common in older texts. For current texts, it should be noted that if these units are used the advantages of the SI are lost. The relation of these units to the SI should be specified in every document in which they are used.

Table 10. Examples of other non-SI units

Name	Symbol	Value in SI units
curie ^(a)	Ci	1 Ci = 3.7×10^{10} Bq
röntgen ^(b)	R	1 R = 2.58×10^{-4} C/kg
rad ^(c,f)	rad	1 rad = 1 cGy = 10^{-2} Gy
rem ^(d,f)	rem	1 rem = 1 cSv = 10^{-2} Sv
X unit ^(e)		1 X unit $\approx 1.002 \times 10^{-4}$ nm
gamma ^(f)	γ	1 γ = 1 nT = 10^{-9} T
jansky	Jy	1 Jy = 10^{-26} W · m ⁻² · Hz ⁻¹
fermi ^(f)		1 fermi = 1 fm = 10^{-15} m
metric carat ^(g)		1 metric carat = 200 mg = 2×10^{-4} kg
torr	Torr	1 Torr = (101 325/760) Pa
standard atmosphere	atm ^(h)	1 atm = 101 325 Pa
calorie	cal	⁽ⁱ⁾
micron ^(f)	μ ^(j)	1 μ = 1 μ m = 10^{-6} m

(a) The curie is a special unit employed in nuclear physics to express activity of radionuclides (12th CGPM, 1964, Resolution 7; CR, 94).

(b) The röntgen is a special unit employed to express exposure to x or γ radiation.

(c) The rad is a special unit employed to express absorbed dose of ionizing radiation.

When there is risk of confusion with the symbol for radian, rd may be used as the symbol for rad.

(d) The rem is a special unit used in radioprotection to express dose equivalent.

(e) The X unit was employed to express the wavelengths of x rays. Its relationship with the SI unit is an approximate one.

(f) Note that this non-SI unit is exactly equivalent to an SI unit with an appropriate submultiple prefix.

(g) The metric carat was adopted by the 4th CGPM in 1907 (CR, 89-91) for commercial dealings in diamonds, pearls and precious stones.

(h) Resolution 4 of the 10th CGPM (1954; CR, 79). The designation “standard atmosphere” for a reference pressure of 101 325 Pa is still acceptable.

(i) Several “calories” have been in use:

- a calorie labelled “at 15 °C”: 1 cal₁₅ = 4.1855 J (value adopted by the CIPM in 1950; PV, 1950, 22, 79-80);
- a calorie labelled “IT” (International Table): 1 cal_{IT} = 4.1868 J (5th International Conference on the Properties of Steam, London, 1956);
- a calorie labelled “thermochemical”: 1 cal_{th} = 4.184 J.

(j) The micron and its symbol, adopted by the CIPM in 1879 (PV, 1879, 41) and repeated in Resolution 7 of the 9th CGPM (1948; CR, 70) were abolished by the 13th CGPM (1967-1968, Resolution 7; CR, 105 and *Metrologia*, 1968, 4, 44).