SI

A concise summary of the International System of Units, SI

Metrology is the science of measurement and its application. Metrology includes all theoretical and practical aspects of measurement, whatever the measurement uncertainty and field of application.

The International Bureau of Weights and Measures (BIPM) was established by Article 1 of the Metre Convention, which was signed on 20 May 1875. It is charged with providing the basis for a single, coherent system of measurements to be used throughout the world and it operates under the authority of the International Committee of Weights and Measures (CIPM).

Table 1 *The seven base units of the SI*

Quantity	**SI unit**
time	The **second**, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the caesium frequency $\Delta\nu_{\text{Cs}}$, the unperturbed ground-state hyperfine transition frequency of the caesium 133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s^{-1}.
length	The **metre**, symbol m, is the SI unit of length. It is defined by taking the fixed numerical value of the speed of light in vacuum c to be 299 792 458 when expressed in the unit m s^{-1}, where the second is defined in terms of $\Delta\nu_{\text{Cs}}$.
mass	The **kilogram**, symbol kg, is the SI unit of mass. It is defined by taking the fixed numerical value of the Planck constant h to be $6.626\,070\,15 \times 10^{-34}$ when expressed in the unit J s, which is equal to $\text{kg m}^2\ \text{s}^{-1}$, where the metre and the second are defined in terms of c and $\Delta\nu_{\text{Cs}}$.
electric current	The **ampere**, symbol A, is the SI unit of electric current. It is defined by taking the fixed numerical value of the elementary charge e to be $1.602\,176\,634 \times 10^{-19}$ when expressed in the unit C, which is equal to A s, where the second is defined in terms of $\Delta\nu_{\text{Cs}}$.
thermodynamic temperature	The **kelvin**, symbol K, is the SI unit of thermodynamic temperature. It is defined by taking the fixed numerical value of the Boltzmann constant k to be $1.380\,649 \times 10^{-23}$ when expressed in the unit J K^{-1}

Although the hertz and the becquerel are both equal to the reciprocal second, hertz is used only for periodic phenomena, and becquerel is used only 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 unit of thermodynamic temperature. The quantity Celsius temperature t is related to thermodynamic temperature T by the equation $t/^{\circ}\mathrm{C} = T/\mathrm{K} - 273.15$.

The sievert is also used for the quantities ‘directional dose equivalent’ and ‘personal dose equivalent’.

There are many more quantities than units. For each quantity, there is only one SI unit (although this may often be expressed in different ways by using the special names), while the same SI unit may be used to express the values of several different quantities (for example, the SI unit J/K may be used to express the value of both heat capacity and entropy). It is therefore important not to use the unit alone to specify the quantity. This applies both to scientific texts and also to measuring instruments (i.e. an instrument read-out should indicate both the quantity concerned and the unit).

There are quantities with the unit one, 1, i.e. ratios of two quantities of the same kind. For example, refractive index is the ratio of two speeds, and relative permittivity is the ratio of the permittivity of a dielectric medium to that of free space. There are also quantities with the character of a count, for example, the number of cellular or biomolecular entities. These quantities also have the unit one. The unit one is by nature an element of any system of units. Quantities with the unit one can therefore be considered as traceable to the SI. However, when expressing the values of dimensionless quantities, the unit 1 is not written.

Decimal multiples and sub-multiples of SI units

A set of prefixes have been adopted for use with the SI units in order to express the values of quantities that are either much larger than, or much smaller than, the SI unit when used without any prefix. They can be used with any SI unit. The SI prefixes are listed in Table 3.

Table 3 *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. 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; or femtosecond, fs.

When the SI units are used without any prefixes, the resulting set of units is described as being **coherent** in the following sense: when only coherent units are used, equations between the numerical values of quantities take exactly the same form as the equations between the quantities themselves. The use of a coherent set of units has technical advantages, for example in algebraic calculus (see the SI Brochure).

The kilogram, kg, is problematic because the name already includes a prefix, 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 it has a distinct advantage for establishing international dialogue. The use of the SI, as a standard system of units, simplifies the teaching of science. For these reasons, the use of SI units is recommended in all fields of science and technology. Other units, i.e. non-SI units, are generally defined in terms of SI units using conversion factors.

Nonetheless, some non-SI units are still widely used. A few, such as the minute, hour and day as units of time, will always be used because they are part of our culture. Others are used for historical reasons, 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 are considered to be best suited to the purpose. However, when non-SI units are used, the correspondence to the SI should always be quoted. A selection of non-SI units is listed in Table 4 with their conversion factors to the SI. For a more comprehensive list, see the SI Brochure.

Table 4 ***A selection of non-SI units***

When units are named after an individual their symbol should begin with a capital letter (for example: ampere, A; kelvin, K; hertz, Hz; or coulomb, C). In all other cases, except the litre, they begin with a lower case letter (for example: metre, m; second, s; or mole, mol). The symbol for the litre is an exception; either a lower case letter ‘l’ or a capital ‘L’ may be used, the capital is allowed in this case to avoid confusion between the lower case letter l and the number one, 1.

The language of science: 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. The number multiplying the unit is the numerical value of the quantity in that unit. A single space is always left between the number and the unit. The numerical value depends on the

In forming products or quotients of unit symbols the normal rules of algebra apply. In forming products of unit symbols, a space should be left between units (or alternatively a half-high centred dot can be used as a multiplication symbol). The importance of the space should be noted: the product of a metre and a second is denoted by m s (with a space), but ms (without a space) is used to denote a millisecond. In addition, when forming complicated products of units, brackets or negative exponents should be used to avoid ambiguities. For example, the molar gas constant R is given by:

$$\begin{aligned} pV_\mathrm{m}/T = R &= 8.314\ \mathrm{Pa\ m^3\ mol^{-1}\ K^{-1}} \\ &= 8.314\ \mathrm{Pa\ m^3/(mol\ K)}. \end{aligned}$$

When formatting numbers, the decimal marker may be either a point (i.e. a full stop) or a comma, depending on the circumstances. For documents in the English language a point is usual, but for many languages and in many countries a comma is usual.

When a number has many digits, it is customary to group the digits into threes about the decimal point to aid readability. This is not essential, but it is often done and is generally helpful. When this format is used, the groups of three digits should be separated only by a space; neither a point nor a comma should be used. The uncertainty in the numerical value of a quantity may often be conveniently shown by giving the uncertainty in the least significant digits in brackets after the number.

For example: The value of the electron mass is given in the 2014 CODATA listing of fundamental constants as

$$m_\mathrm{e} = 9.109\,383\,56\ (11) \times 10^{-31}\ \mathrm{kg},$$

where 11 is the standard uncertainty in the final digits quoted for the numerical value.

For further information, see the BIPM website, or the **SI Brochure** 9th edition, which is available at

www.bipm.org

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