3 DEFINITION OF UNITS AND SYSTEMS OF UNITS

3.1 Systems of units

In a system consisting of a set of physical quantities and the relational equations connecting them, a certain number of quantities are regarded by convention as dimensionally independent and form the set of *base quantities* for the whole system. All other physical quantities are *derived quantities*, defined in terms of the base quantities and expressed algebraically as products of powers of the base quantities.

In a similar way, a *system of units* is based on a set of units chosen by convention to be the units of the base quantities, and all units for derived quantities are expressed as products of powers of the base units, analogous to the corresponding expressions in the system of quantities. When the derived units are expressed in terms of the base units by relations with numerical factors equal to unity, the system and its units are said to be coherent.

The number of base units of the unit system is equal to that of the corresponding set of base quantities. The base units themselves are defined samples of the base quantities.

The expression of a quantity as a product of powers of the base quantities (neglecting their vectorial or tensorial character and all numerical factors including their sign) is called the dimensional product (or the dimension) of the quantity with respect to the chosen set of base quantities or base dimensions. The powers to which the various base quantities or base dimensions are raised are called the dimensional exponents; the quantities and the corresponding units are of the same dimension.

Derived units and their symbols are expressed algebraically in terms of base units by means of the mathematical signs for multiplication and division. Some derived units have received special names and symbols, which can themselves be used to form names and symbols of other derived units (see sections **3.2** and **3.3**).

Physical quantities that have as their dimension a product of powers of the base dimensions with all exponents equal to zero are called dimensionless quantities. The values of dimensionless quantities (*e.g.*, relative density, refractive index) are expressed by pure numbers. The corresponding unit, which is the ratio of a unit to itself, is usually not written; if necessary it may be expressed by the number 1. Since the primary purpose of a system of units is to provide a basis for the transformation of the numerical values of physical quantities under a transformation of units, and since dimensionless quantities are invariant to such a transformation, there is no need to include quantities like plane angle and solid angle in the category of base quantities. Plane angle is

usually considered to be a derived quantity, defined in terms of the ratio of two lengths, and solid angle, a derived quantity defined in terms of the ratio of an area to the square of a lenghth. Nevertheless, in some situations (notably in statistical physics, in particle transport and radiative transfer and particularly in photometry and illumination) the steradian must be treated as a base *unit* in order to avoid ambiguity and to distinguish between units corresponding to different quantities.

3.2 The International System of Units (SI)

The name Système International d'Unités (International System of Units) with the international abbreviation SI was adopted by the Conférence Générale des Poids et Mesures (CGPM) in 1960. It is a coherent system based on the seven base units (CGPM 1960 and 1971) listed in table 4. These units are presently defined in the following way:

1: metre; *mètre*

Le mètre est la longueur du trajet parcouru dans le vide par la lumière pendant une durée de 1/299 792 458 *de seconde.* (17th CGPM (1983), Resolution 1).

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.

2: kilogram; *kilogramme*

Le kilogramme est l'unité de masse; il est égal à la masse du prototype international du kilogramme. (1st CGPM (1889) and 3rd CGPM (1901)).

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

3: second; *seconde*

La seconde est la durée de 9 192 631 770 *périodes de la radiation correspondant à la transition entre les deux niveaux hyperfins de l'état fondamental de l'atome de cesium 133.* (13th CGPM (1967), Resolution 1).

The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.

4: ampere; *ampère*

L'ampère est l'intensité d'un courant constant qui, maintenu dans deux conducteurs parallèles, rectilignes, de longueur infinie, de section circulaire négligeable, et placés à une distance de 1 mètre l'un de l'autre dans le vide, produirait entre ces conducteurs une force égale à 2×10^{-7} *newton par mètre de longueur.* (9th CGPM (1948), Resolutions 2 and 7).

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.

Table 4. SI base units.

Base quantity	Name	Symbol
length *longueur*	metre *mètre*	m
mass *masse*	kilogram *kilogramme*	kg
time *temps*	second *seconde*	s
electric current *courant électrique*	ampere *ampère*	A
thermodynamic temperature *température thermodynamique*	kelvin *kelvin*	K
amount of substance *quantité de matière*	mole *mole*	mol
luminous intensity *intensité lumineuse*	candela *candela*	cd

5: kelvin; *kelvin*

Le kelvin, unité de température thermodynamique, est la fraction 1/273,16 de la température thermodynamique du point triple de l'eau. (13th CGPM (1967), Resolution 4).

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

The 13th CGPM (1967, Resolution 3) also decided that the unit kelvin and its symbol K should be used to express both the thermodynamic temperature and an interval or a difference of temperature.

In addition to the thermodynamic temperature (symbol T) there is also the Celsius temperature (symbol t) defined by the equation

$$t = T - T_0$$

where $T_0 = 273.15\,\mathrm{K}$. Celsius temperature is expressed in degree Celsius; *degré Celsius* (symbol, °C). The unit 'degree Celsius' is equal to the unit 'kelvin', and a temperature interval or a difference of temperature may also be expressed in degrees Celsius.

6: mole; *mole*

1°. *La mole est la quantité de matière d'un système contenant autant d'entités élémentaires qu'il y a d'atomes dans 0,012 kilogramme de carbone 12.*

2°. *Lorsqu'on emploie la mole, les entités élémentaires doivent être spécifiées et peuvent être des atomes, des molécules, des ions, des électrons, d'autres particules ou des groupements spécifiés de telles particules.* (14th CGPM (1971), Resolution 3).

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

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

Note: In this definition, it is understood that the carbon 12 atoms are unbound, at rest and in their ground state.

7: candela; *candela*

La candela est l'intensité lumineuse, dans une direction donnée, d'une source qui émet une radiation monochromatique de fréquence 540 × 10^{12} *hertz et dont l'intensité énergétique dans cette direction est 1/683 watt par stéradian.* (16th CGPM (1979), Resolution 3).

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.

Specific names and symbols have been given to several coherent derived SI units; these derived units are listed in table 5.

3.3 Non-SI units of special interest in physics

Because consistency and uniformity of usage tend to enhance clarity, it is a general rule of SI that the use of non-SI units should be discontinued. However there are some important instances where this is either impractical or inadvisable. The SI recognizes three categories of non-SI units to be used with the SI.

3.3.1 Units accepted for use whose value in SI units is exactly defined

The CIPM (1969) recognized that users of the SI will wish to employ certain units which are important and widely used, but which do not properly fall within the SI. The special names and symbols of those units that have been accepted for continuing use and the corresponding units of the SI are listed in table 6. Although the use of these units is acceptable, their combination with SI units to form incoherent compound units should be authorized only in limited cases.

Decimal multiples or sub-multiples of the time units listed in table 6 should not be formed by using the prefixes given in table 1. Forming symbols for decimal multiples or sub-multiples of units by using the symbols of the prefixes given in table 1 is not possible with superscript symbols, such as °, ′, and ″ for angle units.

Table 5. Derived SI units with special names.

Quantity *Grandeur*	Derived SI unit; *Unité SI dérivée*			
	Name *Nom*	Symbol *Symbole*	Expression in terms of base units *Expression en unités de base*	Expression in terms of other SI units *Expression en d'autres unités SI*
plane angle *angle plan*	radian	rad	m/m	
solid angle *angle solide*	steradian *stéradian*	sr	m^2/m^2	
frequency *fréquence*	hertz	Hz	s^{-1}	
force *force*	newton	N	$m\ kg\ s^{-2}$	J/m
pressure *pression*	pascal	Pa	$m^{-1}\ kg\ s^{-2}$	N/m^2, J/m^3
energy, work, quantity of heat *énergie, travail, quantité de chaleur*	joule	J	$m^2\ kg\ s^{-2}$	N m
power, radiant flux *puissance, flux énergétique*	watt	W	$m^2\ kg\ s^{-3}$	J/s
quantity of electricity, electric charge *quantité d'électricité, charge électrique*	coulomb	C	A s	
electric potential, potential difference, electromotive force *tension électrique, différence de potentiel, force électromotrice*	volt	V	$m^2\ kg\ s^{-3}\ A^{-1}$	W/A, J/C
capacitance *capacité électrique*	farad	F	$m^{-2}\ kg^{-1}\ s^4\ A^2$	C/V
electric resistance *résistance électrique*	ohm	Ω	$m^2\ kg\ s^{-3}\ A^{-2}$	V/A

Table 5. Derived SI units with special names (continued).

Quantity *Grandeur*	Derived SI unit; *Unité SI dérivée*			
	Name *Nom*	Symbol *Symbole*	Expression in terms of base units *Expression en unités de base*	Expression in terms of other SI units *Expression en d'autres unités SI*
conductance *conductance*	siemens	S	$m^{-2}\ kg^{-1}\ s^3\ A^2$	A/V, Ω^{-1}
magnetic flux *flux d'induction magnétique*	weber	Wb	$m^2\ kg\ s^{-2}\ A^{-1}$	V s
magnetic flux density *induction magnétique*	tesla	T	$kg\ s^{-2}\ A^{-1}$	Wb/m^2
inductance *inductance*	henry	H	$m^2\ kg\ s^{-2}\ A^{-2}$	Wb/A
Celsius temperature *température Celsius*	degree Celsius *degré Celsius*	°C	K	
luminous flux *flux lumineux*	lumen	lm	cd sr *	
illuminance *éclairement lumineux*	lux	lx	m^{-2} cd sr *	lm/m^2
activity *activité*	becquerel	Bq	s^{-1}	
absorbed dose** *dose absorbée*	gray	Gy	$m^2\ s^{-2}$	J/kg
dose equivalent** *équivalent de dose*	sievert	Sv	$m^2\ s^{-2}$	J/kg

* The symbol sr must be included here to distinguish luminous flux (lumen) from luminous intensity (candela).

** The dose equivalent is equal to the absorbed dose multiplied by dimensionless factors defining the relative biological effectiveness of the radiation. Although the gray and the sievert have the same expression in terms of base units, they measure conceptually distinct quantities.

Table 6. Commonly used non-SI units.

	Unit; *Unité*		
Quantity *Grandeur*	Name *Nom*	Symbol *Symbole*	Definition *Définition*
plane angle *angle plan*	degree *degré*	°	$1° = \frac{\pi}{180}$ rad
	minute (of angle) *minute (d'angle)*	′	$1' = \frac{1}{60}^{\circ} = \frac{\pi}{10\,800}$ rad
	second (of angle) *seconde (d'angle)*	″	$1'' = \frac{1}{60}' = \frac{\pi}{648\,000}$ rad
time* *temps*	minute *minute*	min	1 min = 60 s
	hour *heure*	h	1 h = 60 min = 3600 s
	day *jour*	d	1 d = 24 h = 86 400 s
volume *volume*	litre *litre*	l, L	1 L = 1 dm^3 = 10^{-3} m^3 ? 1 L = 1,000028 dm^3
mass *masse*	tonne *tonne*	t	1 t = 1 Mg = 1000 kg

* The general symbol for the time unit year (*année*) is a.

Table 7. Units whose values are defined by experiment.
For the values of these units see section **6**, table 10.

	Unit; *Unité*		
Quantity *Grandeur*	Name *Nom*	Symbol *Symbole*	Definition *Définition*
mass *masse*	(unified) atomic mass unit *unité de masse atomique (unifiée)*	u	1 u = m(^{12}C)/12
energy *énergie*	electronvolt *électronvolt*	eV	1 eV= (e/C) J

3.3.2 Units accepted for use whose value expressed in SI units must be obtained by experiment

The units listed in table 7, which are important and widely used for special problems, are also accepted by the CIPM (1969) for continuing use with those of the SI.

3.3.3 Units whose use may be discontinued

In view of existing practice, the CIPM (1978) considered it acceptable to retain for the time being the units listed in table 8 for use with those of the SI, with the exception of the units fermi, torr and calorie. These three units should be avoided in favor of an appropriate SI unit or decimal multiple formed by using the prefixes of table 1. All of the units listed in table 8 may be abandoned in the future; they should not be introduced where they are not already in use at present.

The appearance of the bar in table 8 does not imply a preference for the use of $p_{\circ} = 10^5$ Pa as the thermodynamic standard state pressure. The choice between 10^5 Pa and 101 325 Pa (or any other value) is a matter of convenience, and is not a direct consequence of the choice of units. However, the use of a standard pressure as a *unit* under the name "standard atmosphere" should be avoided.

Table 8. Non-SI units, the use of which may be discontinued.

Quantity *Grandeur*	Unit; *Unité* Name *Nom*	Symbol *Symbole*	Definition *Définition*
length *longueur*	angstrom	Å	1 Å = 10^{-10} m
	fermi	fm *	1 fermi = 10^{-15} m
area *aire*	barn	b	1 b = 100 fm^2 = 10^{-28} m^2
pressure *pression*	bar	bar	1 bar = 10^5 Pa
	torr	Torr	1 Torr = $\frac{101325}{760}$ Pa
quantity of heat *quantité de chaleur*	calorie	cal	1 cal_{IT} = 4.1868 J ** 1 cal_{15} = 4.1855 J ** 1 cal_{th} = 4.184 J **
activity of a radio-active source *activité d'une source radioactive*	curie	Ci	1 Ci = 3.7×10^{10} s^{-1}
exposure of X or γ radiations *exposition des rayonnements* X *ou* γ	roentgen	R	1 R = 2.58×10^{-4} C/kg
absorbed dose *dose absorbée*	rad	rad***, rd	1 rad = 0.01 Gy
dose equivalent *équivalent de dose*	rem	rem	1 rem = 0.01 Sv

* fm is the correct symbol for femtometre (*femtomètre*): 1 fm = 10^{-15} m (see section **1.2.2**, table 1).
** These units are, respectively, the so-called "International Table" calorie, the 15 °C calorie and the thermochemical calorie.
*** The symbol rad should be avoided whenever there is a risk of confusion with the symbol for radian.

4 RECOMMENDED SYMBOLS FOR PHYSICAL QUANTITIES

This section presents a listing of the most commonly used symbols for physical quantities. The list is not intended to contain all of the symbols used in physics; its purpose is to provide a guide for teachers and students, and to facilitate the flow of information across disciplinary boundaries.

Each symbol is listed under that category deemed most appropriate and will generally be repeated in a second category only when such repetition is useful for a logical grouping of related symbols. The emphasis here is on symbols and nomenclature; therefore, an expression given with the name of a symbol should be considered as a description rather than as a definition.

Many of the symbols listed are general; they may be made more specific by adding superscripts or subscripts or by using both lower and upper case forms if there is no ambiguity or conflict with other symbols. Where more than one symbol is given there is no implied preference in the ordering. Symbols in parentheses generally are secondary choices that are available to reduce repeated use of one symbol with different meanings. When there are alternate forms of a Greek letter (*e.g.*, θ, ϑ; ϕ, φ) either or both may be used. The form ϖ of the letter π may be used as if it were a distinct letter.

4.1 Space and time

space coordinates; *coordonnées d'espace*	(x,y,z), (r,θ,ϕ) (x_1,x_2,x_3)
relativistic coordinates; *coordonnées relativistes* : $x_0 = ct,\ x_1 = x,\ x_2 = y,\ x_3 = z,\ x_4 = \mathrm{i}ct$	(x_0,x_1,x_2,x_3) (x_1,x_2,x_3,x_4)
position vector; *vecteur de position*	$\boldsymbol{r}$
length; *longueur*	l, L, a
breadth; *largeur*	b
height; *hauteur*	h
radius; *rayon*	r
thickness; *épaisseur*	d, δ
diameter; *diamètre* : $2r$	d
element of path; *élément de parcours*	$\mathrm{d}s$, $\mathrm{d}l$
area; *aire, superficie*	A, S
volume; *volume*	V, v
plane angle; *angle plan*	α, β, γ, θ, ϕ
solid angle; *angle solide*	Ω, ω
wavelength; *longueur d'onde*	λ
wave number; *nombre d'onde* : $1/\lambda$	σ [1]

[1] In molecular spectroscopy the wave number in vacuum ν/c is denoted by $\bar{\nu}$.