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1 GENERAL RECOMMENDATIONS*

1.1 Physical quantities

There are two somewhat different meanings of the term 'physical quantity'. One refers to the abstract metrological concept (*e.g.*, length, mass, temperature), the other to a specific example of that concept (an attribute of a specific object or system: diameter of a steel cylinder, mass of the proton, critical temperature of water). Sometimes it is important to distinguish between the two and, ideally, it might be useful to be able to do so in all instances. However little is to be gained by attempting to make that distinction in this report. The primary concern here is with symbols and terminology in general; section **6**, however, gives the symbols and numerical values of specific physical constants.

1.1.1 Definitions

A physical quantity** is expressed as the product of a numerical value (*i.e.*, a pure number) and a unit:

$$\text{physical quantity} = \text{numerical value} \times \text{unit}.$$

For a physical quantity symbolized by a, this relationship is represented in the form

$$a = \{a\} \cdot [a],$$

where $\{a\}$ stands for the numerical value of a and $[a]$ stands for the unit of a. Neither the name nor the symbol for a physical quantity should imply any particular choice of unit.

When physical quantities combine by multiplication or division the usual rules of arithmetic apply to both the numerical values and to the units. A quantity which arises (or may be considered to arise) from dividing one physical quantity by another with the same dimension has a unit which may be symbolized by the number 1; such a unit often has no special name or symbol and the quantity is expressed as a pure number.

Examples:

$$E = 200\ \mathrm{J}$$
$$F = 27\ \mathrm{N/m^2} \qquad n = 1.55 \quad \text{(refractive index)}$$
$$f = 3 \times 10^8\ \mathrm{Hz}$$

* For further details see International Standard ISO 31/0-1981: *General Principles Concerning Quantities, Units and Symbols.*

** French: *grandeur physique*; German: *physikalische Grösse*; Italian: *grandezza fisica*; Russian: *fizicheskaya velichina*; Spanish: *magnitud física.*

1.1.2 Symbols

Symbols for physical quantities should be single letters of the Latin or Greek alphabet with or without modifying signs (subscripts, superscripts, primes, etc.). The two-letter symbols used to represent dimensionless combinations of physical quantities are an exception to this rule (see section **4.14** "Dimensionless parameters"). When such a two-letter symbol appears as a factor in a product it should be separated from the other symbols by a dot, by a space, or by parentheses. It is treated as a single symbol and can be raised to a positive or negative power without using parentheses.

Abbreviations (*i.e.*, shortened forms of names or expressions, such as p.f. for partition function) may be used in text, but should not be used in physical equations. Abbreviations in text should be written in ordinary roman type.

Symbols for physical quantities and symbols for numerical variables should be printed in italic (*sloping*) type, while descriptive subscripts and numerical subscripts are to be printed in roman (upright) type.

Examples:

C_g	(g = gas)	C_p
g_n	(n = normal)	$\sum_n a_n \psi_n$
μ_r	(r = relative)	$\sum_r b_r x^r$
E_k	(k = kinetic)	$g_{i,k}$ but $g_{1,2}$
χ_e	(e = electric)	p_χ

It is convenient to use symbols with distinctive typefaces in order to distinguish between the components of a vector (or a tensor) and the vector (or tensor) as an entity in itself, or to avoid the use of subscripts. The following standard conventions should be adhered to whenever the appropriate typefaces are available:

(a) Vectors should be printed in bold italic type, *e.g.*, $\boldsymbol{a}$, $\boldsymbol{A}$.
(b) Tensors should be printed in slanted bold sans serif type, *e.g.*, $\boldsymbol{\mathsf{S}}$, $\boldsymbol{\mathsf{T}}$.

Remark: When such type is not available, a vector may be indicated by an arrow above the symbol: *e.g.*, $\vec{a}$, $\vec{B}$. Second-rank tensors may be indicated by a double arrow or by a double-headed arrow: *e.g.*, $\vec{\vec{S}}$, $\overleftrightarrow{S}$. The extension of this to higher order tensors becomes awkward; in such cases the index notation should be used uniformly for tensors and vectors:

Examples:

$$A_i, \quad S_{ij}, \quad R_{ijkl}, \quad R^{ij}{}_{kl}, \quad R^{i}{}_{.jk.}{}^{l}$$

1.1.3 Simple mathematical operations

Addition and subtraction of two physical quantities are indicated by:

$$a + b \qquad \text{and} \qquad a - b.$$

Multiplication of two physical quantities may be indicated in one of the following ways:

$$ab \qquad a \cdot b \qquad a \times b.$$

Division of one quantity by another quantity may be indicated in one of the following ways:

$$\frac{a}{b} \qquad a/b \qquad ab^{-1}$$

or in any other way of writing the product of a and b^{-1}.

These procedures can be extended to cases where one of the quantities or both are themselves products, quotients, sums or differences of other quantities. If brackets are necessary, they should be used in accordance with the rules of mathematics. When a solidus is used to separate the numerator from the denominator, brackets should be inserted if there is any doubt where the numerator starts or where the denominator ends.

Examples:

Expressions with a horizontal bar	Same expressions with a solidus
$\dfrac{a}{bcd}$	a/bcd or $a/(bcd)$
$\dfrac{2}{9}\sin kx$	$(2/9)\sin kx$
$\dfrac{a}{b} + c$	$a/b + c$
$\dfrac{a}{b - c}$	$a/(b - c)$
$\dfrac{a + b}{c - d}$	$(a + b)/(c - d)$
$\dfrac{a}{b} + \dfrac{c}{d}$	$a/b + c/d$ or $(a/b) + (c/d)$

The argument of a mathematical function is placed in parentheses, brackets or braces, if necessary, in order to define its extent unambiguously.

Examples:

$$\sin\{2\pi(x - x_0)/\lambda\} \qquad \exp\{(r - r_0)/\sigma\}$$
$$\exp[-V(r)/kT] \qquad \surd(G/\rho)$$

Parentheses may be omitted when the argument is a single quantity or a simple product: *e.g.*, $\sin\theta$, $\tan kx$. A horizontal overbar may be used with the square root sign to define the outermost level of aggregation, *e.g.*, $\sqrt{G(t)/H(t)}$, and this may be preferable to $\surd\{G(t)/H(t)\}$.

Table 1. Prefixes for use with SI units.

10^{-1}	deci;	*déci*	d	10^{1}	deca;	*déca*	da
10^{-2}	centi;	*centi*	c	10^{2}	hecto;	*hecto*	h
10^{-3}	milli;	*milli*	m	10^{3}	kilo;	*kilo*	k
10^{-6}	micro;	*micro*	µ	10^{6}	mega;	*méga*	M
10^{-9}	nano;	*nano*	n	10^{9}	giga; *	*giga*	G
10^{-12}	pico;	*pico*	p	10^{12}	tera;	*téra*	T
10^{-15}	femto;	*femto*	f	10^{15}	peta;	*peta*	P
10^{-18}	atto;	*atto*	a	10^{18}	exa;	*exa*	E

* 'giga' is pronounced with the first **g** soft, the second **g** hard.

1.2 Units

1.2.1 Symbols for units

The full name of a unit is always printed in lower case roman (upright) type. If that name is derived from a proper name then its abbreviation is a one or two letter symbol whose first letter is capitalized. The symbol for a unit whose name is not derived from a proper name is printed in lower case roman type.

Examples:

metre, m   ampere, A   watt, W   weber, Wb

Remark: Although by the above rule the symbol for litre is l, in order to avoid confusion between the letter l and the number 1, the symbol may also be written L.

Symbols for units do not contain a full stop (period) and remain unaltered in the plural.

Example:

7 cm   and not   7 cm.   or   7 cms

1.2.2 Prefixes

The prefixes that should be used to indicate decimal multiples or submultiples of a unit are given in table 1. Compound prefixes formed by the juxtaposition of two or more prefixes should not be used.

Not : mµs , *but* : ns (nanosecond)
Not : kMW , *but* : GW (gigawatt)
Not : µµF , *but* : pF (picofarad)

When a prefix symbol is used with a unit symbol the combination should be considered as a single new symbol that can be raised to a positive or negative power without using brackets.

Examples:

cm^3 mA^2 $\mu\mathrm{s}^{-1}$

Remark:

cm^3 means $(0.01\ \mathrm{m})^3 = 10^{-6}\ \mathrm{m}^3$ and never $0.01\ \mathrm{m}^3$
$\mu\mathrm{s}^{-1}$ means $(10^{-6}\ \mathrm{s})^{-1} = 10^{6}\ \mathrm{s}^{-1}$ and never $10^{-6}\ \mathrm{s}^{-1}$

1.2.3 Mathematical operations

Multiplication of two units should be indicated in one of the following ways :

N m   N · m

Division of one unit by another unit should be indicated in one of the following ways:

$\frac{\mathrm{m}}{\mathrm{s}}$ m/s $\mathrm{m\,s}^{-1}$

or by any other way of writing the product of m and s^{-1}. Not more than one solidus should be used in an expression.

Examples:

Not : cm/s/s , *but* : $\mathrm{cm/s}^2$ or $\mathrm{cm\,s}^{-2}$
Not : J/K/mol , *but* : J/(K mol) or $\mathrm{J\,K^{-1}\,mol^{-1}}$

Since the rules of algebra may be applied to units and to physical quantities as well as to pure numbers, it is possible to divide a physical quantity by its unit. The result is the numerical value of the physical quantity in the specified unit system: $\{a\} = a/[a]$. This number is the quantity that is listed in tables or used to mark the axes of graphs. The form "quantity/unit" should therefore be used in the headings of tables and as the labels on graphs for an unambiguous indication of the meaning of the numbers to which it pertains.

Examples:

Given $p = 0.1013$ MPa, then $p/\mathrm{MPa} = 0.1013$
Given $v = 2200$ m/s, then $v/(\mathrm{m/s}) = 2200$
Given $T = 295$ K, then $T/\mathrm{K} = 295$, $1000\,\mathrm{K}/T = 3.3898$

1.3 Numbers

1.3.1 Decimal sign

In most European languages (including Russian and other languages using the Cyrillic alphabet) the decimal sign is a comma on the line (,); this sign is preferred by ISO (ISO 31/0-1981, p. 7) and is used in ISO publications even in English. However, in both American and British English the decimal sign is a dot on the line (.). The centered dot (·) which has sometimes been used in British English, should never be used as a decimal sign in scientific writing.

1.3.2 Writing numbers

Numbers should normally be printed in roman (upright) type. There should always be at least one numerical digit both before and after the decimal sign. An integer should never be terminated by a decimal sign, and if the magnitude of the number is less than unity the decimal sign should be preceded by a zero.

Examples:

35 or 35.0 *but not* 35.   0.0035 *but not* .0035

To facilitate the reading of long numbers (greater than four digits either to the right or to the left of the decimal sign) the digits may be grouped in groups of three separated by a thin space, but no comma or point should be used except for the decimal sign. Instead of a single final digit, the last four digits may be grouped.

Examples:

1987   299 792 458   1.234 567 8 or 1.234 5678

1.3.3 Arithmetical operations

The sign for multiplication of numbers is a cross ($\times$) or a centered dot ($\cdot$); however, when a dot is used as a decimal sign the centered dot should not be used as the multiplication sign.

Examples:

2.3×3.4 or $2,3 \times 3,4$ or $2,3 \cdot 3,4$ or $(137.036)(273.16)$
but not $2.3 \cdot 3.4$

Division of one number by another number may be indicated either by a horizontal bar or by a solidus (/), or by writing it as the product of numerator and the inverse first power of the denominator. In such cases the number under the inverse power should always be placed in brackets, parentheses or other sign of aggregation.

Examples:

$$\frac{136}{273.16} \qquad 136/273.16 \qquad 136\,(273.16)^{-1}$$

As in the case of quantities (see section **1.1.3**), when the solidus is used and there is any doubt where the numerator starts or where the denominator ends, brackets or parentheses should be used.

1.4 Nomenclature for intensive properties

1.4.1 The adjective 'specific' in the English name for an intensive physical quantity should be avoided if possible and should in all cases be restricted to the meaning 'divided by mass' (mass of the system, if this consists of more than one component or more than one phase). In French, the adjective '*massique*' is used with the sense of 'divided by mass' to express this concept.

Examples:

specific volume,	*volume massique*,	volume/mass
specific energy,	*énergie massique*,	energy/mass
specific heat capacity,	*capacité thermique massique*,	heat capacity/mass

1.4.2 The adjective 'molar' in the English name for an intensive physical quantity should be restricted to the meaning 'divided by amount of substance' (the amount of substance of the system if it consists of more than one component or more than one phase).

Examples:

molar mass,	mass/amount of substance
molar volume,	volume/amount of substance
molar energy,	energy/amount of substance
molar heat capacity,	heat capacity/amount of substance

An intensive molar quantity is usually denoted by attaching the subscript m to the symbol for the corresponding extensive quantity (*e.g.*, volume, V; molar volume, $V_{\mathrm{m}} = V/n$). In a mixture the symbol X_{B}, where X denotes an extensive quantity and B is the chemical symbol for a substance, denotes the partial molar quantity of the substance B defined by the relation:

$$X_{\mathrm{B}} = (\partial X/\partial n_{\mathrm{B}})_{T,p,n_{\mathrm{C}},\ldots}.$$

For a pure substance B the partial molar quantity X_{B} and the molar quantity X_{m} are identical. The molar quantity $X_{\mathrm{m}}(\mathrm{B})$ of pure substance B may be denoted by X^{*}_{B}, where the superscript * denotes 'pure', so as to distinguish it from the partial molar quantity X_{B} of substance B in a mixture, which may alternatively be designated X'_{B}.

1.4.3 The noun 'density' in the English name for an intensive physical quantity (when it is not modified by the adjectives 'linear' or 'surface') usually implies 'divided by volume' for scalar quantities but 'divided by area' for vector quantities denoting flow or flux. In French, the adjectives *volumique*, *surfacique*, or *linéique* as appropriate are used with the name of a scalar quantity to express division by volume, area or length, respectively.

Examples:

mass density,	*masse volumique*,	mass/volume
energy density,	*énergie volumique*,	energy/volume

but

current density,	*densité de courant*,	flow/area
surface charge density,	*charge surfacique*,	charge/area

1.5 Dimensional and dimensionless ratios

1.5.1 Coefficients and factors

When a quantity A is proportional to another quantity B, the relationship is expressed by an equation of the form $A = k \cdot B$. The quantity k is usually given the name 'coefficient' or 'modulus' if A and B have different dimensions and 'factor' or 'index' if A and B have the same dimension.

Examples:

$\boldsymbol{E} = A_{\mathrm{H}}(\boldsymbol{B} \times \boldsymbol{J})$	A_{H},	Hall coefficient
$\sigma = E\epsilon$	E,	Young's modulus
$\boldsymbol{J} = -D\,\boldsymbol{\nabla} n$	D,	diffusion coefficient
$L_{12} = k\sqrt{L_1 L_2}$	k,	coupling factor
$F = \mu F_{\mathrm{n}}$	μ,	friction factor

1.5.2 Parameters, numbers and ratios

Certain combinations of physical quantities often are useful in characterizing the behavior or properties of a physical system; it is then convenient to consider such a combination as a new quantity. In general this new quantity is called a 'parameter'; if, however, the quantity is dimensionless it is referred to as a 'number' or a 'ratio'. If such a ratio is inherently positive and less than 1 it is often denoted as a 'fraction'.

Examples:

Grüneisen parameter : γ	$\gamma = \alpha/\kappa\rho c_V$
Reynolds number : Re	$Re = \rho v l/\eta$
mobility ratio : b	$b = \mu_-/\mu_+$
mole fraction : x_{B}	$x_{\mathrm{B}} = n_{\mathrm{B}}/\Sigma_j n_{\mathrm{B}_j}$

2 SYMBOLS FOR ELEMENTS, PARTICLES, STATES AND TRANSITIONS

2.1 Chemical elements

Names and symbols for the chemical elements are given in table 2. Symbols for chemical elements should be written in roman (upright) type. The symbol is not followed by a full stop.

Examples:

Ca   C   H   He

The nucleon number (mass number, baryon number) of a nuclide is shown as a left superscript (*e.g.*, $^{14}\mathrm{N}$).

In nuclear physics, when there will be no confusion with molecular compounds a left subscript may be used to indicate the number of protons and a right subscript to indicate the number of neutrons in the nucleus (*e.g.*, $^{235}_{92}\mathrm{U}_{143}$). Although these subscripts are redundant they are often useful. The right subscript is usually omitted and should never be included unless the left subscript is also present.

The right subscript position is also used to indicate the number of atoms of a nuclide in a molecule (*e.g.*, $^{14}\mathrm{N}_2{}^{16}\mathrm{O}$). The right superscript position should be used, if required, to indicate a state of ionization (*e.g.*, Ca_2^+, PO_4^{3-}) or an excited *atomic* state (*e.g.*, He^*). A metastable *nuclear* state, however, often is treated as a distinct nuclide: *e.g.*, either $^{118}\mathrm{Ag}^{\mathrm{m}}$ or $^{118\mathrm{m}}\mathrm{Ag}$.

Roman numerals are used in two different ways:

i. The spectrum of a z-fold ionized atom is specified by the small capital roman numeral corresponding to $z+1$, written on the line with a thin space following the chemical symbol.

Examples:

H I (spectrum of neutral hydrogen)   Ca II   Al III

ii. Roman numerals in right superscript position are used to indicate the oxidation number.

Examples:

$\mathrm{Pb}_2^{\mathrm{II}}\mathrm{Pb}^{\mathrm{IV}}\mathrm{O}_4$ $\mathrm{K}_6\mathrm{Mn}^{\mathrm{IV}}\mathrm{Mo}_9\mathrm{O}_{32}$