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Quantities and units —

Part 1: **General**

Grandeurs et unités —

Partie 1: Généralités

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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This document was prepared by Technical Committee ISO/TC 12, *Quantities and units*, in collaboration with IEC/TC 25, *Quantities and units*.

This second edition cancels the first edition (ISO 80000-1:2009), which has been technically revised. It also incorporates the Technical Corrigendum ISO 80000-1:2009/Cor.1:2011.

The main changes are as follows:

— More focus on concepts and terminology based on a system of quantities, particularly following the recent major revision of the International System of Units (SI) and the proposed revisions of the International vocabulary of metrology (VIM).

— At the same time, subclauses of previous editions of this document which essentially reproduced content from other sources – particularly metrological vocabulary, descriptions of SI units and compilations of fundamental constants – have been substantially removed from the present edition, in accordance with a resolution taken by ISO/TC 12 in 2020.

A list of all parts in the ISO 80000 and IEC 80000 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

Systems of quantities – as defined in ISO/IEC Guide 99 – can be treated in many consistent, but different, ways. Which treatment to use is partly a matter of convention.

The quantities and relations among the quantities used here are those almost universally accepted for use throughout the physical sciences. They are presented in the majority of scientific textbooks today and are familiar to all scientists and technologists.

The quantities and the relations among them are essentially infinite in number and are continually evolving as new fields of science and technology are developed. Thus, it is not possible to list all these quantities and relations in the ISO/IEC 80000 series; instead, a selection of the more commonly used quantities and the relations among them is presented.

It is inevitable that some readers working in particular specialized fields may find that the quantities they are interested in using may not be listed in this document or in another International Standard. However, provided that they can relate their quantities to more familiar examples that are listed, this will not prevent them from defining units for their quantities.

The system of quantities presented in this document is named the International System of Quantities (ISQ), in all languages. This name was not used in ISO 31 series, from which the present harmonized series has evolved. However, the ISQ does appear in ISO/IEC Guide 99 and is the system of quantities underlying the International System of Units, denoted “SI”, in all languages according to the SI Brochure.

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Quantities and units —

Part 1:
General

1 Scope

This document gives general information and definitions concerning quantities, systems of quantities, units, quantity and unit symbols, and coherent unit systems, especially the International System of Quantities (ISQ).

The principles laid down in this document are intended for general use within the various fields of science and technology, and as an introduction to other parts of this International Standard.

The ISO/IEC 80000 series does not, as yet, cover ordinal quantities and nominal properties.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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ISO/IEC Guide 99, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

BIPM *The International System of Units (SI)*, 9th edition (2019), https://www.bipm.org/en/publications/si-brochure

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/IEC Guide 99 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

4 Quantities

4.1 The concept of quantity

In this document, it is accepted that things (including physical bodies and phenomena, substances, events, etc.) are characterized by properties, according to which things can be compared, in terms of having the same property or not, such as the shape of rigid bodies or the blood group of human beings. Some properties make things comparable also by order, so that for example winds can be compared by their strength and earthquakes can be compared by their magnitude. Finally, some properties make things comparable not only in terms of equivalence and order, but also in more complex ways, and in particular by ratio, as is the case for most physical quantities, according to which the mass or the electric charge of a body might be twice the mass or the electric charge of another body, and so on.

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Not all properties, and more specifically quantities, can be compared with each other. For example, while the diameter of a cylindrical rod can be compared to the height of a block, the diameter of a rod cannot be compared to the mass of a block.

Quantities that are comparable are said to be of the same kind[4] and are instances of the same general quantity. Hence, diameters and heights are quantities of the same kind, being instances of the general quantity length.

It is customary to use the same term, "quantity", to refer to both general quantities, such as length, mass, etc., and their instances, such as given lengths, given masses, etc. Accordingly, we are used to saying both that length is a quantity and that a given length is a quantity, by maintaining the specification – "general quantity, Q" or "individual quantity, Q_a" – implicit and exploiting the linguistic context to remove the ambiguity.

When specific terms are used for quantities, Annex A shall be followed.

4.2 System of quantities ─ Base quantities and derived quantities

A set of quantities and their relations are called a system of quantities. General quantities are related through equations that express laws of nature or define new general quantities. Each equation between quantities is called a quantity equation.

It is convenient to consider some quantities of different kinds as mutually independent. Such quantities are called base quantities. Other quantities, called derived quantities, are defined or expressed in terms of base quantities by means of equations.

It is a matter of choice how many and which quantities are considered to be base quantities. It is also a matter of choice which equations are used to define the derived quantities.

4.3 Universal constants and empirical constants

Some individual quantities are considered to be constant under all circumstances. Such quantities are called universal constants or fundamental physical constants[5].

EXAMPLE 1 The Planck constant, h.

EXAMPLE 2 The Faraday constant, F.

Other quantities may be constant under some circumstances but depend on others. Their values are generally obtained by measurement. They are called empirical constants.

EXAMPLE 3

The result of measuring at a certain location the length l and the periodic time T, for each of several pendulums, can be expressed by one quantity equation

$$T = C\sqrt{l}$$

where C is an empirical constant that depends on the location.

Theory shows that

$$C = \frac{2\pi}{\sqrt{g}}$$

where g is the local acceleration of free fall, which is another empirical constant.

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4.4 Constant multipliers in quantity equations

Equations between quantities sometimes contain constant multipliers. These multipliers depend on the definitions chosen for the quantities occurring in the equations, i.e., on the system of quantities chosen. Such multipliers may be purely numerical and are then called numerical factors.

EXAMPLE 1

In a system of quantities where length, mass, and time are three base quantities, the kinetic energy of a particle in classical mechanics is

$$T = \frac{1}{2} m v^2$$

where T is kinetic energy, m is mass and v is speed. This equation contains the numerical factor $\frac{1}{2}$.

A multiplier may include one or more universal (or empirical) constants.

EXAMPLE 2

The Coulomb law for electric charges in a system of quantities with three base quantities is

$$F = \frac{q_1 q_2}{r^2}$$

where F is scalar force, q_1 and q_2 are two point-like electric charges, r is distance.

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For a rationalised system of quantities with four base quantities, where a base quantity of an electrical nature is added, the expression becomes

$$F = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2}$$

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where ε_0 is, since the 2019 redefinition of SI base units, an empirical constant, i.e., the electric constant (it was formerly a universal constant).

A multiplier may also include one or more conventional quantity values, such as ε_0 in the last example.

Constant multipliers other than numerical factors are often called coefficients (see A.2.2).

4.5 International System of Quantities, ISQ

The special choice of base quantities and quantity equations, including multipliers, given in ISO 80000 and IEC 80000 defines the International System of Quantities (ISQ). Derived quantities can be defined in terms of the base units by quantity equations, see 6.4. There are seven base quantities in the ISQ: length, mass, time, electric current, thermodynamic temperature, amount of substance, and luminous intensity.

5 Dimensions

In the system of quantities under consideration, the relation between any general quantity Q and the base quantities can be expressed by means of an equation. The equation may include a sum of terms, each of which can be expressed as a product of powers of base quantities A, B, C, ... from a chosen set, sometimes multiplied by a numerical factor ξ, i.e., $\xi \cdot A^\alpha B^\beta C^\gamma \cdots$, where the set of exponents α, β, γ, ... is the same for each term.

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The dimension of the quantity Q is then expressed by the dimensional product

$$\dim Q = \mathrm{A}^{\alpha}\,\mathrm{B}^{\beta}\,\mathrm{C}^{\gamma}\ldots$$

where A, B, C, … denote the dimensions of the base quantities A, B, C, …, respectively, and α, β, γ, … are called the dimensional exponents.

Quantities that are of the same kind (e.g., length) have the same dimension, even if they are originally expressed in different units (such as yards and metres). If quantities have different dimensions (such as length vs. mass), they are of different kinds[4][6] and cannot be compared[7].

A quantity whose dimensional exponents are all equal to zero has the dimensional product denoted $\mathrm{A}^0\mathrm{B}^0\mathrm{C}^0\ldots = 1$, where the symbol 1 denotes the corresponding dimension. There is no agreement on how to refer to such quantities. They have been called dimensionless quantities (although this term should now be avoided), quantities with dimension one, quantities with dimension number, or quantities with the unit one. Such quantities are dimensionally simply numbers. To avoid confusion, it is helpful to use explicit units with these quantities where possible, e.g., m/m, nmol/mol, rad, as specified in the SI Brochure. It is especially important to have a clear description of any such quantity when expressing a measurement result.

NOTE 1 These quantities include those defined as a quotient of two quantities of the same dimension and those defined as numbers of entities.

In the ISQ, with the seven base quantities length, mass, time, electric current, thermodynamic temperature, amount of substance and luminous intensity, the dimensions of the base quantities are denoted by L, M, T, I, Θ, N and J, respectively. Hence, in the ISQ, the dimension of a quantity Q in general becomes

$$\dim Q = \mathrm{L}^{\alpha}\mathrm{M}^{\beta}\mathrm{T}^{\gamma}\mathrm{I}^{\delta}\Theta^{\varepsilon}\mathrm{N}^{\zeta}\mathrm{J}^{\eta}$$

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EXAMPLE

Quantity	**Dimension**
speed	LT^{-1}
frequency	T^{-1}
force	LMT^{-2}
energy	$\mathrm{L}^2\mathrm{MT}^{-2}$
entropy	$\mathrm{L}^2\mathrm{MT}^{-2}\Theta^{-1}$
electric tension	$\mathrm{L}^2\mathrm{MT}^{-3}\mathrm{I}^{-1}$
magnetic flux	$\mathrm{L}^2\mathrm{MT}^{-2}\mathrm{I}^{-1}$
illuminance	$\mathrm{L}^{-2}\mathrm{J}$
molar entropy	$\mathrm{L}^2\mathrm{MT}^{-2}\Theta^{-1}\mathrm{N}^{-1}$
efficiency	1

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6 Units

6.1 General

In this clause units are dealt with in relation to systems of quantities. Further guidance about units, given in the SI Brochure, shall be followed.

6.2 Units and numerical values

If a particular instance of a quantity of a given kind is chosen as a reference quantity called the unit, then any other quantity of the same kind can be expressed in terms of this unit, as a product of this unit and a number. That number is called the numerical value of the quantity expressed in this unit.

EXAMPLE 1 The wavelength of one of the sodium spectral lines is

$$\lambda \approx 5{,}896 \times 10^{-7}\ \mathrm{m}$$

Here, λ is the symbol for the quantity wavelength, m is the symbol for the unit of length, the metre, and $5{,}896 \cdot 10^{-7}$ is the numerical value of the wavelength expressed in metres.

In formal treatments, this relation between quantities and units may be expressed[6] in the form

$$Q_\mathrm{a} = \{Q_\mathrm{a}\}\ [Q]$$

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where Q_a is the symbol for an individual quantity, $[Q]$ is the symbol for the unit and $\{Q_\mathrm{a}\}$ is the symbol for the numerical value of the quantity Q_a expressed in the unit $[Q]$. For vectors and tensors, the components are quantities that can be expressed as described above. Vectors and tensors can also be expressed as a numerical value vector or tensor, respectively, multiplied by a unit.

If a quantity is expressed in another unit that is k times the first unit, the new numerical value becomes $1 / k$ times the first numerical value because the quantity, expressed as the product of the numerical value and the unit, is independent of the unit.

EXAMPLE 2

Changing the unit for the wavelength in the previous example from the metre to the nanometre, which is 10^{-9} times the metre, leads to a numerical value which is 10^{9} the numerical value of the quantity expressed in metres.

Thus,

$$\lambda \approx 5{,}896 \times 10^{-7}\ \mathrm{m} = 5{,}896 \times 10^{-7} \times 10^{9}\ \mathrm{nm} = 589{,}6\ \mathrm{nm}$$

It is essential to distinguish between the quantity itself and the numerical value of the quantity expressed in a particular unit. The numerical value of a quantity expressed in a particular unit could be indicated by placing braces (curly brackets) around the quantity symbol and using the unit as a subscript, e.g. $\{\lambda\}_\mathrm{nm}$. It is, however, preferable to indicate the numerical value explicitly as the ratio of the quantity to the unit.

EXAMPLE 3 $\lambda / \mathrm{nm} \approx 589{,}6$

This notation is particularly recommended for use in graphs and headings of columns in tables.

6.3 Mathematical operations

The product and the quotient of two quantities, Q_1 and Q_2, satisfy the relations

$$Q_1 Q_2 = \{Q_1\}\ \{Q_2\} \cdot [Q_1]\ [Q_2]$$

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$$\frac{Q_1}{Q_2} = \frac{\{Q_1\}}{\{Q_2\}} \cdot \frac{[Q_1]}{[Q_2]}$$

Thus, the product $\{Q_1\}$ $\{Q_2\}$ is the numerical value $\{Q_1Q_2\}$ of the quantity Q_1Q_2, and the product $[Q_1]$ $[Q_2]$ is the unit $[Q_1Q_2]$ of the quantity Q_1Q_2. Similarly, the quotient $\{Q_1\}$ / $\{Q_2\}$ is the numerical value $\{Q_1 / Q_2\}$ of the quantity Q_1 / Q_2, and the quotient $[Q_1]$ / $[Q_2]$ is the unit $[Q_1 / Q_2]$ of the quantity Q_1 / Q_2. Units such as $[Q_1]$ $[Q_2]$ and $[Q_1]$ / $[Q_2]$ are called compound units.

EXAMPLE 1

The speed, v, of a particle in uniform motion is given by

$$v = \frac{l}{t}$$

where l is the distance travelled in the duration t.

Thus, if the particle travels a distance l = 6 m in the duration t = 2 s, the speed, v, is equal to

$$v = l / t = (6\ \mathrm{m}) / (2\ \mathrm{s}) = 3\ \mathrm{m} / \mathrm{s}$$

NOTE A quantity defined as A / B is called “quotient of A by B” or “A per B”, but not “A per unit B”.

Equations between numerical values, such as $\{Q_1Q_2\} = \{Q_1\}\ \{Q_2\}$, are called numerical value equations. Equations between units, such as $[Q_1Q_2] = [Q_1]\ [Q_2]$, are called unit equations.

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The arguments of exponential functions, logarithmic functions, trigonometric functions, etc., are numbers, numerical values, or combinations of quantities with a dimensional product equal to one (see Clause 5).

EXAMPLE 2

$\exp(E / kT)$; $\ln(p / \mathrm{kPa})$; $\sin(\pi / 3)$; $\cos(\omega t + \alpha)$

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6.4 Quantity equations and numerical value equations

The three types of equations introduced in 4.2 and 6.3, i.e., quantity equations, numerical value equations, and unit equations, are used in science and technology. Quantity equations and numerical value equations are generally used; unit equations are used less frequently. Numerical value equations (and of course unit equations) depend on the choice of units, whereas quantity equations have the advantage of being independent of this choice. Therefore, the use of quantity equations is normally preferred and is strongly recommended.

EXAMPLE

A simple quantity equation is

$$v = \frac{l}{t}$$

as given in 6.3, example 1.

Using, for example, kilometre per hour (symbol km / h), metre (symbol m) and second (symbol s) as the units for speed, distance, and duration, respectively, the following numerical value equation is derived:

$$\{v\}_{\mathrm{km/h}} = 3{,}6 \cdot \{l\}_{\mathrm{m}} / \{t\}_{\mathrm{s}}$$

where $\{v\}_{\mathrm{km/h}} = v / (\mathrm{km} / \mathrm{h})$.

The number 3,6 that occurs in this numerical value equation results from the particular units chosen; with other choices, it would generally be different.

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