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Quantities and units of electricity and magnetism

Grandeurs et unités d'électricité et de magnétisme

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FOREWORD

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up 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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 31/V was developed by Technical Committee ISO/TC 12, *Quantities, units, symbols, conversion factors and conversion tables*, and was circulated to the member bodies in October 1975.

It has been approved by the member bodies of the following countries :

Australia	Germany, F. R.	Romania
Austria	Ghana	South Africa, Rep. of
Belgium	Hungary	Sweden
Brazil	India	Switzerland
Bulgaria	Israel	Turkey
Canada	Italy	United Kingdom
Czechoslovakia	Mexico	U.S.A.
Denmark	Netherlands	Yugoslavia
Finland	Norway	
France	Poland	

The member bodies of the following countries expressed disapproval of the document on technical grounds :

Japan*
U.S.S.R.

* Disagreement concerning the decimal marker only.

This International Standard cancels and replaces ISO Recommendation R 31/V-1965, of which it constitutes a technical revision.

Printed in Switzerland

Quantities and units of electricity and magnetism

INTRODUCTION

This document, containing a table of *quantities and units of electricity and magnetism*, is part V of ISO 31, which deals with quantities and units in the various fields of science and technology. The complete list of parts of ISO 31 is as follows :

Part 0 : *General introduction — General principles concerning quantities, units and symbols.*

Part I : *Quantities and units of space and time.*

Part II : *Quantities and units of periodic and related phenomena.*

Part III : *Quantities and units of mechanics.*

Part IV : *Quantities and units of heat.*

Part V : *Quantities and units of electricity and magnetism.*

Part VI : *Quantities and units of light and related electromagnetic radiations.*

Part VII : *Quantities and units of acoustics.*

Part VIII : *Quantities and units of physical chemistry and molecular physics.*

Part IX : *Quantities and units of atomic and nuclear physics.*

Part X : *Quantities and units of nuclear reactions and ionizing radiations.*

Part XI : *Mathematical signs and symbols for use in the physical sciences and technology.*

Part XII : *Dimensionless parameters.*

Part XIII : *Quantities and units of solid state physics.*

Arrangement of the tables

The tables of quantities and units in ISO 31 are arranged so that the quantities are presented on left-hand pages and the units on corresponding right-hand pages.

All units between two full lines belong to the quantities between the corresponding full lines on the left-hand page.

Where the numbering of the items has been changed in the revision of a part of ISO 31, the number in the preceding edition is shown in parentheses on the left-hand page under the new number for the quantity; a dash is used to indicate that the item in question did not appear in the preceding edition.

Tables of quantities

The most important quantities within the field of this document are given together with their symbols and, in most cases, definitions. These definitions are given merely for identification; they are not intended to be complete.

The vectorial character of some quantities is pointed out, especially when this is needed for the definitions, but no attempt is made to be complete or consistent.

In most cases, only one symbol for the quantity is given[1]; where two or more symbols are given for one quantity and no special distinction is made, they are on an equal footing.

1) When two types of sloping letters exist (for example as with θ, ϑ; φ, ϕ; g, g), only one of these is given; this does not mean that the other is not equally acceptable.

Tables of units

Units for the corresponding quantities are given together with the international symbols and the definitions. For further information, see also Part 0.

The units are arranged in the following way :

1) The names of the SI units are given in large print (larger than text size). The SI units and their decimal multiples and sub-multiples formed by means of the SI prefixes are particularly recommended. The decimal multiples and sub-multiples are not explicitly mentioned.

2) The names of non-SI units which may be used together with SI units because of their practical importance or because of their use in specialized fields are given in normal print (text size).

3) The names of non-SI units which may be used temporarily together with SI units are given in small print (smaller than text size).

The units in classes 2 and 3 are separated by a broken line from the SI units for the quantities concerned.

4) Non-SI units which should not be used together with SI units are given in annexes in some parts of ISO 31. The annexes are not integral parts of the standards. They are arranged in three groups :

a) *Units of the CGS system with special names*

It is generally preferable not to use CGS units with special names and symbols together with SI units.

b) *Units based on the foot, pound and second and some other units*

c) *Other units*

These are given for information, especially regarding the conversion factor. The use of those units marked with † is deprecated.

Remark on supplementary units

The General Conference for Weights and Measures has classified the SI units, radian and steradian, as "supplementary units", deliberately leaving open the question of whether they are base units or derived units, and consequently the question of whether angle and solid angle are to be considered as base quantities or derived quantities.

In ISO 31, plane angle and solid angle are treated as derived quantities (see also Part 0). In ISO 31, they are defined as ratios of two lengths and two areas respectively, and consequently they are treated as dimensionless quantities. Although in this treatment the coherent unit for both quantities is the number 1, it is convenient to use the special names radian and steradian instead of the number 1 in many practical cases.

If plane angle and solid angle were treated as base quantities, the units radian and steradian would be base units and could not be considered as special names for the number 1. Such a treatment would require extensive changes in ISO 31.

Number of digits in numerical statements[1)]

All numbers in the column "Definition" are exact.

In the column "Conversion factors", the conversion factors on which the calculation of others is based are normally given to seven significant digits. When they are exact and contain seven or fewer digits and where it is not obvious from the context, the word "exactly" is added, but when they can be terminated after more than seven digits, they may be given in full. When the conversion factors are derived from experiment, they are given with the number of significant digits justified by the accuracy of the experiments. Generally, this means that in such cases the last digit only is in doubt. When, however, experiment justifies more than seven digits, the factor is usually rounded off to seven significant digits.

The other conversion factors are given to not more than six significant digits; when they are exactly known and contain six or fewer digits, and where it is not obvious from the context, the word "exactly" is added.

Numbers in the column "Remarks" are given to a precision appropriate to the particular case.

SPECIAL REMARKS

Items in the field of electrotechnology in this document are generally in conformity with the recommendations in IEC Publication 27-1. If a name or a symbol in a table is not in accordance with what is given by IEC, this is indicated in the Remarks column.

Equations and quantities

For electricity and magnetism, different systems of equations have been developed depending on the number and the particular choice of base quantities on which the system of equations is founded. For the purpose of explaining this document, only the following systems need be mentioned :

I. System of equations with four base quantities

In the four-dimensional system of equations with four base quantities, one electric quantity is included in the base set. The base quantities are chosen to be : length, time, mass and electric current. In this system the permittivity and the permeability appear as dimensional quantities in the relevant equations.

The equations are always written in a form which is called rationalized, because in the equations factors 4π and 2π appear only in cases involving spherical or circular symmetry respectively.

1) The decimal sign is a comma on the line. In documents in the English language, a comma or a dot on the line may be used.

This rationalized system of equations based on four base quantities is most commonly used in practical calculations in physical sciences and technology.

The use of this system is especially recommended.

II. Systems of equations with three base quantities

These are presented for information in annexes A and B, which are not integral parts of the International Standard. They are not given by IEC in Publication 27-1.

Units

The quantities which belong to the four-dimensional system should be measured in units of the sub-system of the International System of Units[1)] with the four base units :

metre, kilogram, second and ampere.

Alternating current technology

Items 5-40.1 to 5-44.1 in the table deal with sinusoidally varying quantities. For such quantities, lower-case letters are used for instantaneous values, upper-case letters are used for effective (root-mean-square) values, and lower-case letters with a subscript m are used for maximum values. For other choices of symbols and for further information, including cases where the quantities are not sinusoidal, see IEC Publication 27.

1) See also ISO 1000.

Quantities
5-1.1 . . . 5-7.1

5. Electricity and Magnetism

Item No.	Number in IEC Publication 27-1	Quantity	Symbol	Definition	Remarks
5-1.1	67	electric current	I		In alternating current technology, i is used for the instantaneous value of electric current
5-2.1	52	electric charge, quantity of electricity	Q	Integral of electric current over time	
5-3.1	54	volume density of charge, charge density	ρ, (η)	Charge divided by volume	IEC does not give "charge density"
5-4.1	53	surface density of charge	σ	Charge divided by surface area	
5-5.1	55	electric field strength	E, (K)	Force, exerted by electric field on an electric point charge, divided by the electric charge	
5-6.1	56	electric potential	V, φ	For electrostatic fields, a scalar quantity, the gradient of which, with reversed sign, is equal to the electric field strength	IEC gives φ as reserve symbol
5-6.2	57	potential difference, tension	U, (V)	The potential difference between point 1 and point 2 is the line integral from 1 to 2 of the electric field strength : $\varphi_1 - \varphi_2 = \int_1^2 E_s \, ds$	In alternating current technology, u is used for the instantaneous value of potential difference. IEC also gives "voltage"
5-6.3	58	electromotive force	E	The electromotive force of a source is the energy supplied by the source divided by the electric charge transported through the source	
5-7.1	60	electric flux density, displacement	D	The electric flux density is a vector quantity, the divergence of which is equal to the charge density	See 5-10.1

5. Electricity and Magnetism

Units
5-1.a ... 5-7.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
5-1.a	ampere	A	The ampere is that constant electric 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		
5-2.a	coulomb	C	1 C = 1 A·s		The unit ampere hour, 1 A·h = 3,6 kC, is sometimes used
5-3.a	coulomb per cubic metre	C/m^3			
5-4.a	coulomb per square metre	C/m^2			
5-5.a	volt per metre	V/m	1 V/m = 1 N/C		
5-6.a	volt	V	1 V = 1 W/A		
5-7.a	coulomb per square metre	C/m^2			

Quantities
5-8.1 . . . 5-17.1

5. Electricity and magnetism (continued)

Item No.	Number in IEC Publication 27-1	Quantity	Symbol	Definition	Remarks
5-8.1 (5-9.1)	59	electric flux, (flux of displacement)	Ψ	The electric flux across a surface element is the scalar product of the surface element and the electric flux density	IEC does not give "(flux of displacement)"
5-9.1 (5-11.1)	61	capacitance	C	Charge divided by potential difference	
5-10.1 (5-12.1)	62	permittivity	ϵ	Electric flux density divided by electric field strength	IEC also gives "absolute permittivity, (capacitivity)"
5-10.2 (5-12.2)	206	permittivity of vacuum, electric constant	ϵ_0		$\epsilon_0 = 1/\mu_0 c^2$ $= (8{,}854\ 187\ 818 \pm 0{,}000\ 000\ 071) \times 10^{-12}$ F/m[1)] IEC recommends that if distinction is made between permittivity of vacuum and electric constant, the symbol Γ_e be used for the latter
5-11.1 (5-14.1)	63	relative permittivity	ϵ_r	$\epsilon_r = \epsilon/\epsilon_0$	This quantity is dimensionless. IEC also gives "(relative capacitivity)"
5-12.1 (5-15.1)	63a	electric susceptibility	χ, χ_e	$\chi = \epsilon_r - 1$	This quantity is dimensionless
5-13.1 (5-17.1)	65	electric polarization	P	$P = D - \epsilon_0 E$	IEC gives D_i as reserve symbol
5-14.1 (5-18.1)	66	electric dipole moment	p, (p_e)	The electric dipole moment is a vector quantity, the vector product of which with the electric field strength is equal to the torque	
5-15.1 (5-19.1)	68	current density	J, (S)	A vector quantity the integral of which over a given surface is equal to the current flowing through that surface	j is also used
5-16.1 (5-20.1)	69	linear current density	A, (α)	Current divided by the width of conducting sheet	
5-17.1 (5-21.1)	70	magnetic field strength	H	The magnetic field strength is an axial vector quantity, the curl (rotation) of which is equal to the current density, including the displacement current	

1) CODATA BULLETIN 11 (1973)

5. Electricity and Magnetism (continued)

Units
5-8.a . . . 5-17.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
5-8.a	coulomb	C			
5-9.a	farad	F	1 F = 1 C/V		
5-10.a	farad per metre	F/m			
5-13.a	coulomb per square metre	C/m^2			
5-14.a	coulomb metre	C·m			
5-15.a	ampere per square metre	A/m^2			
5-16.a	ampere per metre	A/m			
5-17.a	ampere per metre	A/m			

Quantities
5-18.1 . . . 5-23.2

5. **Electricity and Magnetism** (continued)

Item No.	Number in IEC Publication 27-1	Quantity	Symbol	Definition	Remarks
5-18.1 (5-23.1)	71	magnetic potential difference	U_m	The magnetic potential difference between point 1 and point 2 is the line integral from 1 to 2 of the magnetic field strength	IEC gives also U as symbol and $\mathcal{U}$ as reserve symbol
5-18.2 (5-23.2)	72	magnetomotive force	F, F_m	$F = \oint H_s \, ds$	IEC gives $\mathcal{F}$ as reserve symbol.
5-18.3 (–)	72 a	current linkage	Θ	The net electric conduction current through a closed loop	When Θ results from N equal currents I, $\Theta = NI$
5-19.1 (5-24.1)	73	magnetic flux density, magnetic induction	B	The magnetic flux density is an axial vector quantity such that the force exerted on an element of current is equal to the vector product of this element and the magnetic flux density	
5-20.1 (5-25.1)	74	magnetic flux	Φ	The magnetic flux across a surface element is the scalar product of the surface element and the magnetic flux density	
5-21.1 (5-26.1)	75	magnetic vector potential	A	The magnetic vector potential is a vector quantity, the curl (rotation) of which is equal to the magnetic flux density	
5-22.1 (5-27.1)	76	self inductance	L	For a conducting loop, the magnetic flux through the loop, caused by the current in the loop, divided by this current	
5-22.2 (5-27.2)	77	mutual inductance	M, L_{12}	For two conducting loops, the magnetic flux through one loop, due to the current in the other loop, divided by this current	
5-23.1 (5-28.1)	78	coupling coefficient	k, (κ)	$k = L_{12}/\sqrt{L_1 L_2}$	These quantities are dimensionless
5-23.2 (5-28.2)	79	leakage coefficient	σ	$\sigma = 1 - k^2$	

5. Electricity and Magnetism (continued)

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
5-18.a	ampere	A			
5-19.a	tesla	T	1 T = 1 N/(A·m) = 1 Wb/m² = 1 V·s/m²		
5-20.a	weber	Wb	1 Wb = 1 V·s		
5-21.a	weber per metre	Wb/m			
5-22.a	henry	H	1 H = 1 Wb/A = 1 V·s/A		