IEC 80000-6

Edition 2.0 2022-11

INTERNATIONAL STANDARD

NORME INTERNATIONALE

Quantities and units –
Part 6: Electromagnetism

Grandeurs et unités –
Partie 6: Électromagnétisme

IEC 80000-6:2022-11(en-fr)

IEC Secretariat
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 01.040.29; 17.220.01

ISBN 978-2-8322-5706-7

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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QUANTITIES AND UNITS –

Part 6: Electromagnetism

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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IEC 80000-6 has been prepared by IEC technical committee 25: Quantities and units, and their letter symbols in close cooperation with ISO/TC 12, Quantities and units. It is an International Standard.

This second edition of IEC 80000-6 cancels and replaces the first edition published in 2008. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) With the new definitions in SI, some previously exact values for quantities now must be determined experimentally while other quantities are given as exact values;
b) Item 6-2.2, elementary charge added;
c) Item 6-11.4, induced voltage, added;
d) Index of entries added;
e) Editorial alignment to other parts of the IEC and ISO 80000 series.

The text of this International Standard is based on the following documents:

Draft	Report on voting
25/732/FDIS	25/740/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

IEC 80000 consists of the following parts, under the general title *Quantities and units*:

1) *Part 6: Electromagnetism*
2) *Part 13: Information science and technology*
3) *Part 15: Logarithmic and related quantities, and their units*
4) *Part 16: Printing and writing rules*
5) *Part 17: Time dependency*

The following parts are published by ISO:

1) *Part 1: General*
2) *Part 2: Mathematical signs and symbols to be used in the natural sciences and technology*
3) *Part 3: Space and time*
4) *Part 4: Mechanics*
5) *Part 5: Thermodynamics*
6) *Part 7: Light*
7) *Part 8: Acoustics*
8) *Part 9: Physical chemistry and molecular physics*
9) *Part 10: Atomic and nuclear physics*
10) *Part 11: Characteristic numbers*
11) *Part 12: Condensed matter physics*

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

0.1 Tables of quantities

The names in English of the most important quantities within the field of this document are given together with their symbols and, in most cases, their definitions. The definitions are given for identification of the quantities in the International System of Quantities (ISQ), listed in Table 1; they are not intended to be complete.

The scalar, vectorial or tensorial character of quantities is pointed out, especially when this is needed for the definitions.

In most cases, only one name and only one symbol for the quantity are given; where two or more names or two or more symbols are given for one quantity and no special distinction is made, they are on an equal footing. When two types of italic letters exist (for example as with ϑ and θ; φ and ϕ; *a* and a; *g* and g) only one of these is given. This does not mean that the other is not equally acceptable. It is recommended that such variants should not be given different meanings. A symbol within parenthesis implies that it is an alternative symbol, to be used when, in a particular context, the main symbol is in use with a different meaning.

0.2 Units

0.2.1 General

The names of units for the corresponding quantities are given together with the international symbols and the definitions. These unit names are language-dependent, but the symbols are international and the same in all languages. For further information, see the SI Brochure (9th edition 2019) from BIPM and ISO 80000-1.

The units are arranged in the following way:

a) The base SI units are given first. The SI units have been adopted by the General Conference on Weights and Measures (Conférence Générale des Poids et Mesures, CGPM). The use of base SI units, and their decimal multiples and submultiples formed with the SI prefixes are recommended, although the decimal multiples and submultiples are not explicitly mentioned. The order of the units is kg, m, s, A, K, mol, cd.
b) Some non-SI units are then given, being those accepted by the International Committee for Weights and Measures (Comité International des Poids et Mesures, CIPM), or by the International Organization of Legal Metrology (Organisation Internationale de Métrologie Légale, OIML), or by ISO and IEC, for use with the SI.
c) Non-SI units that are not recommended are given only in annexes in some parts of ISO 80000 and IEC 80000. These annexes are informative, in the first place for the conversion factors, and are not integral parts of the standard. These deprecated units are arranged in two groups:
   1) units in the CGS system with special names, see Annex A;
   2) units based on the foot, pound, and some other related units.

0.2.2 Remark on units for quantities of dimension one, or dimensionless quantities

The coherent unit for any quantity of dimension one, also called a dimensionless quantity, is the number one, symbol 1. When the value of such a quantity is expressed, the unit symbol 1 is generally not written out explicitly.

EXAMPLE

Refractive index n = 1,53 × 1 = 1,53

Prefixes shall not be used to form multiples or submultiples of this unit. Instead of prefixes, powers of 10 are recommended.

EXAMPLE

Reynolds number Re = 1,32 × 10^3

Considering that plane angle is generally expressed as the ratio of two lengths and solid angle as the ratio of two areas, in 1995 the CGPM specified that, in the SI, the radian, symbol rad, and steradian, symbol sr, are dimensionless derived units. This implies that the quantities plane angle and solid angle are considered as derived quantities of dimension one. The units radian and steradian are thus equal to one; they may either be omitted, or they may be used in expressions for derived units to facilitate distinction between quantities of different kinds, but having the same dimension.

0.3 Numerical statements in this document

The sign = is used to denote "is exactly equal to" and the sign ≈ is used to denote "is approximately equal to".

Numerical values of physical quantities that have been experimentally determined always have an associated measurement uncertainty. This uncertainty should always be specified. In this document, the magnitude of the uncertainty is represented as in the following example.

EXAMPLE

l = 2,347 82(32) m

In this example, $l = a(b)$ m, the numerical value of the uncertainty b indicated in parentheses is assumed to apply to the last (and least significant) digits of the numerical value a of the length l. This notation is used when b represents one standard uncertainty (estimated standard deviation) in the last digits of a. The numerical example given above can be interpreted to mean that the best estimate of the numerical value of the length l, when l is expressed in the unit metre, is 2,347 82 and that the unknown value of l is believed to lie between (2,347 82 −0,000 32) m and (2,347 82 +0,000 32) m with a probability determined by the standard uncertainty 0,000 32 m and the probability distribution of the values of l.

0.4 Special remarks

0.4.1 General

The items given in IEC 80000-6 are generally in conformity with the International Electrotechnical Vocabulary (IEV), especially IEC 60050-121 and IEC 60050-131. For each quantity, the reference to IEV is given in the form: "See IEC 60050-121:20XX, 121-xx-xxx.".

The font used for text is sans serif; that used for quantities is serif.

0.4.2 System of quantities

For electromagnetism, several different systems of quantities have been developed and used depending on the number and the choice of base quantities on which the system is based. However, in electromagnetism and electrical engineering, only the International System of Quantities, ISQ, and the associated International System of Units, SI, are acknowledged and are reflected in the standards of ISO and IEC. The SI has seven base units, among them are the kilogram (kg), the metre (m), the second (s), and the ampere (A).

0.4.3 Sinusoidal quantities

For quantities that vary sinusoidally with time, and for their complex representations, the IEC has standardized two ways to build symbols. Capital and lowercase letters are generally used for electric current (item 6-1) and for voltage (item 6-11.3), and additional symbols for other quantities. These are given in IEC 60027-1.

EXAMPLE 1

The sinusoidal variation with time of an electric current (item 6-1) can be expressed in real representation as

$$i = \sqrt{2}\ I \cos(\omega t - \varphi)$$

and its complex representation (termed phasor) is expressed as

$$\underline{i} = I\ \mathrm{e}^{-\mathrm{j}\varphi}$$

where i is the instantaneous value of the current, I, is its root-mean-square (RMS) value (see 0.4.4), $(\omega t - \varphi)$ is the phase, φ is the initial phase, and j is the imaginary unit ($\mathrm{j}^2 = -1$), in mathematics often denoted by i.

EXAMPLE 2

The sinusoidal variation with time of a magnetic flux (item 6-22.1) can be expressed in real representation as

$$\Phi = \hat{\Phi} \cos(\omega t - \phi) = \sqrt{2}\ \Phi_{\mathrm{eff}} \cos(\omega t - \phi)$$

where Φ is the instantaneous value of the flux, $\hat{\Phi}$ is its peak value and Φ_{eff} is its RMS value.

0.4.4 Root-mean-square value, RMS value

For a time-depending quantity a, the positive square root of the mean value of the square of the quantity taken over a given time interval is called root-mean-square value, i.e.

$$\sqrt{\frac{1}{T}\int_0^T a^2 \mathrm{d}t}$$

The root-mean-square value of a periodic quantity is usually taken over an integration interval, the range of which is the period multiplied by a natural number. For a sinusoidal quantity $a(t) = \hat{A} \cos(\omega t + \varphi)$, the root-mean-square value is $\hat{A}/\sqrt{2}$.

The root-mean-square value of a quantity may be denoted by adding one of the subscripts "eff" or "RMS" to the symbol of the quantity. In electrical technology, the root-mean-square values of electric current $i(t)$ and voltage $u(t)$ are usually denoted I and U, respectively.

QUANTITIES AND UNITS –

Part 6: Electromagnetism

1 Scope

This part of IEC 80000 gives names, symbols, and definitions for quantities and units of electromagnetism. Where appropriate, conversion factors are also given.

This document is based on classical electromagnetism, i.e. mainly Maxwell's equations. No reference is made to quantum field theories.

2 Normative references

There are no normative references in this document.

3 Names, symbols, definitions and units of quantities

The names, symbols, and definitions for quantities and units of electromagnetism are given in the tables on the following pages. For units in the CGS system with special names, see Annex A.

NOTE 1 In general, these quantities can depend on time even when not explicitly noted. All surfaces are assumed to be oriented surfaces (see IEC 60050-102, item 102-04-37)

NOTE 2 The font in the formulas is different from the font of the main text.

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

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

Table 1 – Quantities and units in electromagnetism

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition	Symbol	
6-1	electric current	I i	scalar quantity equal to the quotient of the net quasi-infinitesimal (see IEC 60050-121, item 121-11-06) electric charge dQ (item 6-2.1) transferred through a surface during a quasi-infinitesimal time interval and the duration dt of that interval: $I = \frac{dQ}{dt}$	A	Electric current is one of the base quantities in the International System of Quantities, ISQ, on which the International System of Units, SI, is based. Electric current I through a surface S can also be written as $I = \int_S \boldsymbol{J} \cdot \boldsymbol{e}_n \, dA$ where $\boldsymbol{J}$ is the electric current density (item 6-8) and where $\boldsymbol{e}_n dA$ is the vector surface element. Electric current produces a magnetic field. For related definitions, see item 6-8 and IEC 60050-121:1998, 121-11-13.
6-2.1	electric charge	Q q	additive scalar quantity attributed to any particle and, generally, any system of them, to characterize its electromagnetic interactions	C A s s A	To denote a point charge, q is often used, as is done in this document. Electromagnetic interactions are Coulomb-Lorentz forces, see IEC 60050 121:1998, 121-11-20. The coherent SI unit of charge is coulomb, C. Another frequently used unit is the ampere-hour (Ah) mentioned in IEC 60050-313:2020, 313-01-16, widely used for battery characteristics.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition	Symbol	
6-2.2	elementary charge	e	magnitude of the negative electric charge carried by a single electron, which has charge −1 e	C A s s A	In the SI system the elementary charge, e, is one of the fundamental constants with an exact value e = 1,602 176 634 × 10^{-19} C, see the SI Brochure. Electric charge can be positive, negative or zero. The sign convention is such that the elementary electric charge, e, of the proton, is positive. See IEC 60050-113, item 113-02-12.
6-3	electric charge density, volumic electric charge volumic charge	ρ	scalar quantity representing the spatial distribution of electric charge, $\rho(\boldsymbol{r}) = \frac{\mathrm{d}Q}{\mathrm{d}V}$ where dQ is quasi-infinitesimal (see IEC 60050-121:2008, 121-11-06) electric charge (item 6-2.1) contained in a quasi-infinitesimal 3D domain located at position $\boldsymbol{r}$ and dV is quasi-infinitesimal volume (ISO 80000-3) of this domain	C/m^3 m^{-3} s A	See IEC 60050-121:1998, 121-11-07.
6-4	surface density of electric charge, areic electric charge areic charge	σ	scalar quantity representing the areal distribution of electric charge, $\sigma = \sigma(\boldsymbol{r}) = \frac{\mathrm{d}Q}{\mathrm{d}A}$ where dQ is a quasi-infinitesimal (see IEC 60050-121:2008, 121-11-06) electric charge (item 6-2.1) contained in a quasi-infinitesimal 2D domain located at position $\boldsymbol{r}$, and dA is a quasi-infinitesimal area (ISO 80000-3) of this domain	C/m^2 m^{-2} s A	See IEC 60050-121:1998, 121-11-08.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition	Symbol	
6-5	linear density of electric charge, lineic electric charge lineic charge	τ	scalar quantity representing the linear distribution of electric charge, $\tau = \tau(\boldsymbol{r}) = \frac{dQ}{dl}$ where dQ is a quasi-infinitesimal (see IEC 60050-121:2008, 121-11-06) electric charge (item 6-2.1) contained in a quasi-infinitesimal domain located at position $\boldsymbol{r}$ and dl is a quasi-infinitesimal length (ISO 80000-3) of this domain	C/m m^{-1} s A	See IEC 60050-121, item 121-11-09.
6-6	electric dipole moment	$\boldsymbol{p}$	vector quantity given by $\boldsymbol{p} = q(\boldsymbol{r}_+ - \boldsymbol{r}_-)$ where $\boldsymbol{r}_+$ and $\boldsymbol{r}_-$ are the position vectors (ISO 80000-3) of the carriers of electric charges q and $-q$ (item 6-2), respectively	C m m s A	The electric dipole moment of a substance within a domain is the vector sum of electric dipole moments of all electric dipoles contained in the domain. See IEC 60050-121:1998, 121-11-35 and 121-11-36.
6-7	electric polarization	$\boldsymbol{P}$	vector quantity representing the spatial distribution of electric dipole moment, $\boldsymbol{P}(\boldsymbol{r}) = \frac{d\boldsymbol{p}}{dV}$ where $d\boldsymbol{p}$ is quasi-infinitesimal (see IEC 60050-121:2008, 121-11-06) electric dipole moment (item 6-6) of a substance in a quasi-infinitesimal domain at position $\boldsymbol{r}$ and dV is quasi-infinitesimal volume (ISO 80000-3) of this domain	C/m^2 m^{-2} s A	See IEC 60050-121:1998, 121-11-37.
6-8	electric current density	$\boldsymbol{J}$	vector quantity equal to the sum, for the charge carriers within a volume element of quasi-infinitesimal volume V, of the products of their electric charge Q_i and their velocity $\boldsymbol{v}_i$, divided by the volume V, given by $\boldsymbol{J}(\boldsymbol{r}) = \boldsymbol{J} = \rho \boldsymbol{v}$ where i is the rank of the charge carrier	A/m^2 m^{-2} A	There can be different charge carriers with different velocities. Electric current I (item 6-1) through a surface S is $I = \int_S \boldsymbol{J} \quad \boldsymbol{e}_n dA$ where $\boldsymbol{e}_n dA$ is the vector surface element. See IEC 60050-121:1998, 121-11-11.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition	Symbol	
6-9	linear electric current density	$\boldsymbol{J}_S$	vector quantity equal to the sum, for the charge carriers confined to a surface element of quasi-infinitesimal area S, of the products of their electric charge Q_i and their velocity $\boldsymbol{v}_i$, divided by the area S $\boldsymbol{J}_S(\boldsymbol{r}) = \boldsymbol{J}_S = \sigma\boldsymbol{v}$ where i is the rank of the charge carrier	A/m m^{-1} A	See IEC 60050-121:1998, 121-11-12.
6-10	electric field strength	$\boldsymbol{E}$	additive vector field quantity that exerts on any charged particle located at position $\boldsymbol{r}$ a force $\boldsymbol{F}$ (ISO 80000-4) equal to the product of $\boldsymbol{E}$ and electric charge q (item 6-2.1) of the particle, thus: $\boldsymbol{E}(\boldsymbol{r}) = \frac{\boldsymbol{F}}{q}$	V/m kg m s^{-3} A^{-1}	See IEC 60050-121:1998, 121-11-18.
6-11.1	electric potential	V φ	scalar quantity expressed by $-\mathbf{grad}\ V = \boldsymbol{E} + \frac{\partial \boldsymbol{A}}{\partial t}$ where $\boldsymbol{E}$ is electric field strength (item 6-10), $\boldsymbol{A}$ is magnetic vector potential (item 6-32) and t is time (ISO 80000-3)	V kg m^2 s^{-3} A^{-1}	The electric potential is not unique since any constant scalar field quantity can be added to it without changing its gradient. The electric potential, the electric field, and the magnetic vector potential depend on the position. See IEC 60050-121:1998, 121-11-25.
6-11.2	electric potential difference	V_{ab}	scalar quantity given by $V_{ab} = V_a - V_b$ where V_a and V_b are the electric potentials (item 6-11.1) at points a and b, respectively	V kg m^2 s^{-3} A^{-1}	$V_{ab} = \int_{\boldsymbol{r}_a(C)}^{\boldsymbol{r}_b} \left(\boldsymbol{E} + \frac{\partial \boldsymbol{A}}{\partial t}\right) \cdot d\boldsymbol{r}$ where $\boldsymbol{E}$ is electric field strength (item 6-10), $\boldsymbol{A}$ is magnetic vector potential (item 6-32), t is time (ISO 80000-3), and $\boldsymbol{r}$ is the position vector (ISO 80000-3) along a given curve C, from point a to point b. See IEC 60050-121, item 121-11-26.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition	Symbol	
6-11.3	voltage, electric tension	U U_{ab}, u	for a conductor, scalar quantity given by the electric potential difference V_{ab} (6-11.2) between two points a and b respectively	V kg m^2 s^{-3} A^{-1}	The name "voltage", commonly used in the English language, is given in the IEV, but it is an exception to the principle that a quantity name should not refer to any name of a unit. See IEC 60050-121:2002, 121-11-27.
6-11.4	induced voltage	U_i	negative of time derivative of protoflux (item 6-22.2) $U_i = -\frac{d}{dt}\int_C \boldsymbol{A} \cdot d\boldsymbol{r}$	V kg m^2 s^{-3} A^{-1}	If the integration path is closed, the loop voltage is $U_l = -\frac{d}{dt}\oint_C \boldsymbol{A} \cdot d\boldsymbol{r} = -\frac{d\Phi}{dt}$
6-12	electric flux density, electric displacement	$\boldsymbol{D}$	vector quantity given by $\boldsymbol{D} = \varepsilon_0 \boldsymbol{E} + \boldsymbol{P}$ where ε_0 is electric constant (item 6-14.1), $\boldsymbol{E}$ is electric field strength (item 6-10), and $\boldsymbol{P}$ is electric polarization (item 6-7)	C/m^2 m^{-2} s A	The electric flux density is related to electric charge density via **div** $\boldsymbol{D} = \rho$ where **div** denotes divergence. The electric flux density, the electric field strength, and the polarization depend on the position. See IEC 60050-121:1998, 121-11-40.
6-13	capacitance	C	for a capacitive element, quotient of electric charge Q and voltage U (item 6-11.3); $C = \frac{Q}{U}$	F kg^{-1} m^{-2} s^4 A^2	The electric charge of a capacitive element is given by the time integral of the electric current. See IEC 60050-131:2008, 131-12-11.
6-14.1	electric constant, permittivity of vacuum	ε_0	scalar quantity given by $\varepsilon_0 = \frac{1}{\mu_0 c_0^2}$ where μ_0 is the magnetic constant (item 6-26.1) and c_0 is luminal speed (item 6-35.2)	F/m kg^{-1} m^{-3} s^4 A^2	See IEC 60050-121:2021, 121-11-03. This quantity is considered to be constant in time.