

# ISO

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION

## ISO RECOMMENDATION

### R 31

PART V

## QUANTITIES AND UNITS OF ELECTRICITY AND MAGNETISM

1st EDITION

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## BRIEF HISTORY

The ISO Recommendation R 31, *Part V – Quantities and Units of Electricity and Magnetism*, was drawn up by Technical Committee ISO/TC 12, *Quantities, Units, Symbols, Conversion Factors and Conversion Tables*, the Secretariat of which is held by the Danish Standards Association, Dansk Standardiseringsråd (DS).

Work on this question by the Technical Committee began in 1957. The ISO/TC 12 Secretariat drew up three draft proposals in succession; the last one was adopted, in 1960, as a Draft ISO Recommendation.

It should be noted that the following international organizations have had these draft proposals sent to them and have taken part in the discussions at the meetings of Technical Committee ISO/TC 12:

International Committee on Weights and Measures,  
International Electrotechnical Commission,  
International Union of Pure and Applied Chemistry,  
International Union of Pure and Applied Physics  
and its Sub-Committee SUN,  
International Commission on Illumination,  
Comité international de métrologie légale,  
World Meteorological Organization,  
International Commission on Radiological Units and Measurements,  
International Telegraph and Telephone Consultative Committee.

In June 1961, this Draft ISO Recommendation (No. 439) was circulated to all the ISO Member Bodies for enquiry. It was approved, subject to some modifications of an editorial nature, by the following Member Bodies:

|                |             |                |
|----------------|-------------|----------------|
| Australia      | Hungary     | Poland         |
| Austria        | India       | Portugal       |
| Belgium        | Israel      | Romania        |
| Canada         | Italy       | Sweden         |
| Chile          | Japan       | Switzerland    |
| Czechoslovakia | Mexico      | U. A. R.       |
| Denmark        | Netherlands | United Kingdom |
| France         | New Zealand | U. S. A.       |
| Greece         | Norway      | Yugoslavia     |

Three Member Bodies apposed the approval of the Draft:

Germany, Ireland, U. S. S. R.

The Draft ISO Recommendation was then submitted by correspondence to the ISO Council which decided, in November 1965, to accept it as an ISO RECOMMENDATION.

# Introduction

## General remarks

This document, containing a table of *Quantities and Units of Electricity and Magnetism*, is part of a more comprehensive publication dealing with quantities and units in various fields of science and technology. Other parts of this more comprehensive publication are at present

ISO Recommendation R 31,

Part I (2nd edition): *The International System of Units and Quantities and Units of Space and Time*<sup>1)</sup>,

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 VII: *Quantities and Units of Acoustics*,

Part XI: *Mathematical Signs and Symbols for use in Physical Sciences and Technology*.

General information regarding the arrangement of the tables and the symbols and abbreviations used is to be found in the Introduction to ISO/R 31/Part I, where the full definitions of fundamental units are given as an appendix.

The statements in the definition columns for quantities are given merely for identification; they are not intended to be complete definitions.

## Special remarks

This document follows, unless the contrary is indicated, the IEC<sup>2)</sup> recommendations concerning the quantities and units of electricity and magnetism. In particular, the units of the Giorgi or MKSA system recommended by the IEC are given preference by placing them first and by printing the item number in heavy type. These units belong to the International System of Units adopted by the Conférence Générale des Poids et Mesures.

Items relating to units corresponding to those of the “symmetric” CGS unit system are marked with an asterisk (\*). Items and remarks relating to non-rationalized quantities are also marked with the same asterisk.

Other items for which no recommendations appear in the relevant IEC publications are marked with a dagger (†). Individual significant deviations from IEC recommendations are also marked with the same dagger.

The numerical value of the velocity of light in vacuo, expressed in centimetres per second, is often needed for the conversion factors. For simplicity, in this document, this number is denoted by  $\zeta$ .

## Explanatory remarks concerning quantities, equations and units in this document

In the field of electricity and magnetism, several systems of equations expressing the relations between physical quantities are used. As these equations have to be used only with corresponding unit systems, it is necessary in this Introduction to refer to the different systems of equations used in this field and their relation to the unit systems.

<sup>1)</sup> The title of the first edition of this document was: “Fundamental Quantities and Units of the MKSA system and Quantities and Units of Space and Time”.

<sup>2)</sup> International Electrotechnical Commission (IEC).

## Equations and quantities

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

### I. Systems of equations with four basic quantities

In the equations with four basic quantities, at least one electric quantity is included in the basic set. In such a system the permittivity and the permeability in vacuo appear explicitly as physical quantities in the relevant equations. Two different forms of equations, based on the same set of four basic quantities, are in use:

- I. 1 The *rationalized system of equations*, called “rationalized”, because in these equations factors  $4\pi$  or  $2\pi$  only appear in cases involving spherical or circular symmetry respectively.  
This rationalized system of equations is most commonly used in practical calculations in physics and in electrical technology.
- I. 2 The *non-rationalized system of equations*, in which the factors  $4\pi$  and  $2\pi$  often appear in equations, where they would not be expected.

The equations and quantities given in the tables all belong to these two systems of equations. Where in the document there is a “rationalized” and a corresponding “non-rationalized” quantity, the word “rationalized” is generally omitted from the name of the former. Non-rationalized quantities are denoted in this document by symbols bearing a prime.

The use of rationalized equations is especially recommended.

### II. Systems of equations with three basic quantities

Different systems of equations have been developed for electric and magnetic phenomena with only three basic quantities.

- II. a The *electrostatic system of equations*, defining the electric charge on the basis of Coulomb’s law for the force between two electric charges, by taking the permittivity in vacuo to be a dimensionless quantity, equal to unity.
- II. b The *electromagnetic system of equations*, defining the electric currents on the basis of the law for the force between two electric currents, by taking the permeability in vacuo to be a dimensionless quantity, equal to unity.
- II. c The *symmetric system of equations*, using the electric quantities from system II. a, and the magnetic quantities from system II. b. As a result of combining the two sets of quantities, the velocity of light in vacuo appears explicitly in some of the equations combining electric with magnetic quantities.

Also for these systems of equations founded on three basic quantities two versions, a rationalized and a non-rationalized version, are possible. However, only the non-rationalized version has been commonly used.

For reasons of brevity, only equations founded on four basic quantities have been included in the tables. Since, however, in atomic and nuclear physics, a system of equations founded on three basic quantities, in particular the “symmetric” system (II. c), is commonly used, some of the essential equations of this latter system are given in the appendix, see page 18.

## Units

The quantities occurring in the tables have to be measured in units belonging to a unit system founded on four basic units. The following four basic units of the International System of Units are used as the basic units for electricity and magnetism (MKSA system):

metre, kilogramme, second and ampere.

The quantities occurring in the three systems of equations founded on three basic quantities have to be measured respectively in units of

- a. the electrostatic CGS system,
- b. the electromagnetic CGS system,
- c. the “symmetric” CGS system (or “Gauss system”),

each of which is founded on the three basic units:

centimetre, gramme and second.

Some units of the “symmetric” CGS system have been indicated in the remarks column.

In order to relate the units of these CGS systems to the corresponding units of the MKSA system, the tables contain also units of the following two systems:

- A. the system founded on the four basic units:

centimetre, gramme, second and franklin,

- B. the system founded on the four basic units:

centimetre, gramme, second and biot,

where the franklin and the biot are units of charge and current respectively, as defined in the tables. The relations between the units of the systems A and B and those of the MKSA system can be expressed in the form of equations with conversion factors which are pure numbers. The franklin and the biot correspond respectively to the electrostatic CGS unit of charge and the electromagnetic CGS unit of current. From these correspondences others follow; beneath the names of the units for the systems A and B, there are given in square brackets the names of the corresponding units of the electrostatic or the electromagnetic CGS systems. In the remarks column, these corresponding units are expressed in terms of CGS units of mechanics.

The tables contain in general the units of the system A for quantities related to electrostatics and those of the system B for quantities related to magnetism. This selection corresponds to the “symmetric CGS unit system” (or “Gauss system”) which should be used in connection with the “symmetric” system of equations II. c. A particular exception is the occurrence of the unit biot (corresponding to the electromagnetic CGS unit of electric current) item No. 5-1.c; where it is introduced for the purpose of giving its definition.

For the rationalized quantities, only the MKSA units have been given. For the non-rationalized quantities, the units of the systems A or B are given. This does not imply that these latter units can not be used for rationalized quantities.

## 5. Electricity and Magnetism

| Item No. | Quantity                                 | Symbol       | Definition <sup>1)</sup>                                                                                                        | Remarks             |
|----------|------------------------------------------|--------------|---------------------------------------------------------------------------------------------------------------------------------|---------------------|
| 5-1.1    | electric current                         | $I$          |                                                                                                                                 | $I = \frac{dQ}{dt}$ |
| 5-2.1    | electric charge, quantity of electricity | $Q$          |                                                                                                                                 | $Q = \int Idt$      |
| 5-3.1    | volume density of charge, charge density | $\rho$       | Charge divided by volume.                                                                                                       |                     |
| 5-4.1    | surface density of charge                | $\sigma$     | Charge divided by surface area.                                                                                                 |                     |
| 5-5.1    | electric field strength                  | $E, (K)$     | Force, exerted by electric field on an electric charge, divided by that charge.                                                 |                     |
| 5-6.1    | electric potential                       | $V, \varphi$ | For electrostatic fields, a scalar quantity the gradient of which, with reversed sign, is equal to the electric field strength. |                     |
| 5-6.2    | 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.           |                     |
| 5-6.3    | electromotive force                      | $E$          |                                                                                                                                 |                     |

<sup>1)</sup> The statements in this column are given merely for identification and they are not intended to be complete definitions.