INTERNATIONAL STANDARD

ISO 80000-10

Second edition
2019-08

Quantities and units —

Part 10:
Atomic and nuclear physics

Grandeurs et unités —

Partie 10: Physique atomique et nucléaire

Reference number
ISO 80000-10:2019(E)

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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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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.

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

This second edition cancels and replaces the first edition (ISO 80000-10:2009), which has been technically revised.

The main changes compared to the previous edition are as follows:

— the table giving the quantities and units has been simplified;

— some definitions and the remarks have been stated physically more precisely;

— definitions in this document have been brought in line with their equivalent ones in ICRU 85a.

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

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.

Introduction

0 Special remarks

0.1 Quantities

Numerical values of physical constants in this document are quoted in the consistent values of the fundamental physical constants published in CODATA recommended values. The indicated values are the last known before publication. The user is advised to refer to the CODATA website for the latest values, https://physics.nist.gov/cuu/Constants/index.html.

The symbol $\hbar$ is the reduced Planck constant, it is equal to $\frac{h}{2\pi}$, where h is the Planck constant.

0.2 Special units

1 eV is the energy acquired by an electron in passing a potential difference of 1 V in vacuum.

0.3 Stochastic and non-stochastic quantities

Differences between results from repeated observations are common in physics. These can arise from imperfect measurement systems, or from the fact that many physical phenomena are subject to inherent fluctuations. Quantum-mechanical issues aside, one often needs to distinguish between a *stochastic* quantity, the values of which follow a probability distribution, and a *non-stochastic* quantity with its unique, expected value (expectation) of such distributions. In many instances the distinction is not significant because the probability distribution is very narrow. For example, the measurement of an electric current commonly involves so many electrons that fluctuations contribute negligibly to inaccuracy in the measurement. However, as the limit of zero electric current is approached, fluctuations can become manifest. This case, of course, requires a more careful measurement procedure, but perhaps more importantly illustrates that the significance of stochastic variations of a quantity can depend on the magnitude of the quantity. Similar considerations apply to ionizing radiation; fluctuations can play a significant role, and in some cases need to be considered explicitly. Stochastic quantities, such as the energy imparted and the specific energy imparted (item 10-81.2) but also the number of particle traversals across microscopic target regions and their probability distributions, have been introduced as they describe the discontinuous nature of the ionizing radiations as a determinant of radiochemical and radiobiological effects. In radiation applications involving large numbers of ionizing particles, e.g. in medicine, radiation protection and materials testing and processing, these fluctuations are adequately represented by the expected values of the probability distributions. “Non-stochastic quantities” such as particle fluence (item 10-43), absorbed dose (item 10-81.1) and kerma (item 10-86.1) are based on these expected values.

This document contains definitions based on a differential quotient of the type $\mathrm{d}A/\mathrm{d}B$ in which the quantity A is of a stochastic nature, a situation common in ionizing radiation metrology. In these cases, quantity A is understood as the expected or mean value whose element ΔA falls into element ΔB. The differential quotient $\mathrm{d}A/\mathrm{d}B$ is the limit value of the difference quotient $\Delta A/\Delta B$ for $\Delta B \to 0$. In the remarks of the definitions falling in this category, a reference to this paragraph is made.

Quantities and units —

Part 10:
Atomic and nuclear physics

1 Scope

This document gives names, symbols, definitions and units for quantities used in atomic and nuclear physics. Where appropriate, conversion factors are also given.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

The names, symbols, and definitions for quantities and units used in atomic and nuclear physics are given in Table 1.

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

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

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

Table 1 — Quantities and units used in atomic and nuclear physics

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-1.1	atomic number, proton number	Z	number of protons in an atomic nucleus	1	A nuclide is a species of atom with specified numbers of protons and neutrons. Nuclides with the same value of Z but different values of N are called isotopes of an element. The ordinal number of an element in the periodic table is equal to the atomic number. The atomic number equals the quotient of the charge (IEC 80000-6) of the nucleus and the elementary charge (ISO 80000-1).
10-1.2	neutron number	N	number of neutrons in an atomic nucleus	1	Nuclides with the same value of N but different values of Z are called isotones. $N - Z$ is called the neutron excess number.
10-1.3	nucleon number, mass number	A	number of nucleons in an atomic nucleus	1	$A = Z + N$ Nuclides with the same value of A are called isobars.
10-2	rest mass, proper mass	$m(\mathrm{X})$ m_X	for particle X, mass (ISO 80000-4) of that particle at rest in an inertial frame	kg u Da	EXAMPLE $m(\mathrm{H_2O})$ for a water molecule, m_e for an electron. Rest mass is often denoted m_0. 1 u is equal to 1/12 times the mass of a free carbon 12 atom, at rest and in its ground state. 1 Da = 1 u
10-3	rest energy	E_0	energy E_0 (ISO 80000-5) of a particle at rest: $E_0 = m_0 c_0^2$ where m_0 is the rest mass (item 10-2) of that particle, and c_0 is speed of light in vacuum (ISO 80000-1)	J N m kg m^2 s^{-2}	

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-4.1	atomic mass	$m(\mathrm{X})$ m_X	rest mass (item 10-2) of an atom X in the ground state	kg u Da	$\frac{m(\mathrm{X})}{m_\mathrm{u}}$ is called the relative atomic mass. 1 u is equal to 1/12 times the mass of a free carbon 12 atom, at rest and in its ground state. 1 Da = 1 u
10-4.2	nuclidic mass	$m(\mathrm{X})$ m_X	rest mass (item 10-2) of a nuclide X in the ground state	kg u Da	1 u is equal to 1/12 times the mass of a free carbon 12 atom, at rest and in its ground state. 1 Da = 1 u
10-4.3	unified atomic mass constant	m_u	1/12 of the mass (ISO 80000-4) of an atom of the nuclide $^{12}\mathrm{C}$ in the ground state at rest	kg u Da	1 u is equal to 1/12 times the mass of a free carbon 12 atom, at rest and in its ground state. 1 Da = 1 u
10-5.1	elementary charge	e	one of the fundamental constants in the SI system (ISO 80000-1), equal to the charge of the proton and opposite to the charge of the electron	C s A	
10-5.2	charge number, ionization number	c	for a particle, quotient of the electric charge (IEC 80000-6) and the elementary charge (ISO 80000-1)	1	A particle is said to be electrically neutral if its charge number is equal to zero. The charge number of a particle can be positive, negative, or zero. The state of charge of a particle may be presented as a superscript to the symbol of that particle, e.g. H^+, He^{++}, Al^{3+}, Cl^-, S^{--}, N^{3-}.

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-6	Bohr radius	a_0	radius (ISO 80000-3) of the electron orbital in the hydrogen atom in its ground state in the Bohr model of the atom: $a_0 = \frac{4\pi\varepsilon_0\hbar^2}{m_e e^2}$ where ε_0 is the electric constant (IEC 80000-6), $\hbar$ is the reduced Planck constant (ISO 80000-1), m_e is the rest mass (item 10-2) of electron, and e is the elementary charge (ISO 80000-1)	m Å	The radius of the electron orbital in the H atom in its ground state is a_0 in the Bohr model of the atom. ångström (Å), 1 Å: = 10^{-10} m
10-7	Rydberg constant	R_∞	spectroscopic constant that determines the wave numbers of the lines in the spectrum of hydrogen: $R_\infty = \frac{e^2}{8\pi\varepsilon_0 a_0 h c_0}$ where e is the elementary charge (ISO 80000-1), ε_0 is the electric constant (IEC 80000-6), a_0 is the Bohr radius (item 10-6), h is the Planck constant (ISO 80000-1), and c_0 is the speed of light in vacuum (ISO 80000-1)	m^{-1}	The quantity $R_y = R_\infty h c_0$ is called the Rydberg energy.

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-8	Hartree energy	E_H E_h	energy (ISO 80000-5) of the electron in a hydrogen atom in its ground state: $E_H = \frac{e^2}{4\pi\varepsilon_0 a_0}$ where e is the elementary charge (ISO 80000-1), ε_0 is the electric constant (IEC 80000-6), and a_0 is the Bohr radius (item 10-6)	eV J kg m^2 s^{-2}	The energy of the electron in an H atom in its ground state is E_H.
10-9.1	magnetic dipole moment <atomic physics>	$\boldsymbol{\mu}$	for a particle, vector (ISO 80000-2) quantity causing a change to its energy (ISO 80000-5) ΔW in an external magnetic field of field flux density $\boldsymbol{B}$ (IEC 80000-6): $\Delta W = -\boldsymbol{\mu} \cdot \boldsymbol{B}$	m^2 A	For an atom or nucleus, this energy is quantized and can be written as: $W = g\, \mu_x\, M\, B$ where g is the appropriate g factor (item 10-14.1 or item 10-14.2), μ_x is mostly the Bohr magneton or nuclear magneton (item 10-9.2 or item 10-9.3), M is magnetic quantum number (item 10-13.4), and B is magnitude of the magnetic flux density. See also IEC 80000-6.
10-9.2	Bohr magneton	μ_B	magnitude of the magnetic moment of an electron in a state with orbital angular momentum quantum number l=1 (item 10-13.3) due to its orbital motion: $\mu_B = \frac{e\hbar}{2m_e}$ where e is the elementary charge (ISO 80000-1), $\hbar$ is the reduced Planck constant (ISO 80000-1), and m_e is the rest mass (item 10-2) of electron	m^2 A	

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-9.3	nuclear magneton	μ_N	absolute value of the magnetic moment of a nucleus: $\mu_N = \frac{e\hbar}{2m_p}$ where e is the elementary charge (ISO 80000-1), $\hbar$ is the reduced Planck constant (ISO 80000-1), and m_p is the rest mass (item 10-2) of proton	m^2 A	Subscript N stands for nucleus. For the neutron magnetic moment, subscript n is used. The magnetic moments of protons and neutrons differ from this quantity by their specific g factors (item 10-14.2).
10-10	spin	$\boldsymbol{s}$	vector (ISO 80000-2) quantity expressing the internal angular momentum (ISO 80000-4) of a particle or a particle system	kg m^2 s^{-1}	Spin is an additive vector quantity.
10-11	total angular momentum	$\boldsymbol{J}$	vector (ISO 80000-2) quantity in a quantum system composed of the vectorial sum of angular momentum $\boldsymbol{L}$ (ISO 80000-4) and spin $\boldsymbol{s}$ (item 10-10)	J s eV s kg m^2 s^{-1}	In atomic and nuclear physics, orbital angular momentum is usually denoted by $\boldsymbol{l}$ or $\boldsymbol{L}$. The magnitude of $\boldsymbol{J}$ is quantized so that: $\boldsymbol{J}^2 = \hbar^2 j(j+1)$ where j is the total angular momentum quantum number (item 10-13.6). Total angular momentum and magnetic dipole moment have the same direction. j is not the magnitude of the total angular momentum $\boldsymbol{J}$ but its projection onto the quantization axis, divided by $\hbar$.

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-12.1	gyromagnetic ratio, magnetogyric ratio, gyromagnetic coefficient	γ	proportionality constant between the magnetic dipole moment and the angular momentum: $\boldsymbol{\mu} = \gamma \boldsymbol{J}$ where $\boldsymbol{\mu}$ is the magnetic dipole moment (item 10-9.1), and $\boldsymbol{J}$ is the total angular momentum (item 10-11)	A m^2 J^{-1} s^{-1} A s/kg kg^{-1} s A	1 A·m^2/(J·s) = 1 A·s/kg = 1 T^{-1}·s^{-1} The systematic name is “gyromagnetic coefficient”, but “gyromagnetic ratio” is more usual. The gyromagnetic ratio of the proton is denoted by γ_p. The gyromagnetic ratio of the neutron is denoted by γ_n.
10-12.2	gyromagnetic ratio of the electron, magnetogyric ratio of the electron, gyromagnetic coefficient of the electron	γ_e	proportionality constant between the magnetic dipole moment and the angular momentum of the electron $\boldsymbol{\mu} = \gamma_e \boldsymbol{J}$ where $\boldsymbol{\mu}$ is the magnetic dipole moment (item 10-9.1), and $\boldsymbol{J}$ is the total angular momentum (item 10-11)	A m^2 J^{-1} s^{-1} A s/kg kg^{-1} s A	1 A·m^2/(J·s) = 1 A·s/kg = 1 T^{-1}·s^{-1}

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-13.1	quantum number	N L M j s F	number describing a particular state of a quantum system	1	Electron states determine the binding energy $E = E(n,l,m,j,s,f)$ in an atom. Upper case letters N, L, M, J, S, F are usually used for the whole system. The spatial probability distribution of an electron is given by $\|\Psi\|^2$, where Ψ is its wave function. For an electron in an H atom in a non-relativistic approximation, the wave function can be presented as: $\psi(r,\vartheta,\phi)=R_{nl}(r)\cdot Y_l^m(\vartheta,\phi)$ where r,ϑ,ϕ are spherical coordinates (ISO 80000-2) with respect to the nucleus and to a given (quantization) axis, $R_{nl}(r)$ is the radial distribution function, and $Y_l^m(\vartheta,\phi)$ are spherical harmonics. In the Bohr model of one-electron atoms, n, l, and m define the possible orbits of an electron about the nucleus.
10-13.2	principal quantum number	n	atomic quantum number related to the number n−1 of radial nodes of one-electron wave functions	1	In the Bohr model, $n = 1,2,\ldots,\infty$ is related to the binding energy of an electron and the radius of spherical orbits (principal axis of the elliptic orbits). For an electron in an H atom, the semi-classical radius of its orbit is $r_n = a_0 n^2$ and its binding energy is $E_n = E_H/n^2$.

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-13.3	orbital angular momentum quantum number	l l_i L	atomic quantum number related to the orbital angular momentum l of a one-electron state	1	$\|\boldsymbol{l}\|^2 = \hbar^2 l(l-1)$, $l = 0, 1, \ldots, n-1$ where $\boldsymbol{l}$ is the orbital angular momentum and $\hbar$ is the reduced Planck constant (ISO 80000-1). If reference is made to a specific particle i, the symbol l_i is used instead of l; if reference is made to the whole system, the symbol L is used instead of l. An electron in an H atom for $l = 0$ appears as a spherical cloud. In the Bohr model, it is related to the form of the orbit.
10-13.4	magnetic quantum number	m m_i M	atomic quantum number related to the z component l_z, j_z or s_z, of the orbital, total, or spin angular momentum	1	$l_z = m_l \hbar$, $j_z = m_j \hbar$, and $s_z = m_s \hbar$, with the ranges from $-l$ to l, from $-j$ to j, and ±1/2, respectively. m_i refers to a specific particle i. M is used for the whole system. Subscripts l, s, j, etc., as appropriate, indicate the angular momentum involved. $\hbar$ is the reduced Planck constant (ISO 80000-1).
10-13.5	spin quantum number	s	characteristic quantum number s of a particle, related to its spin (item 10-10), $\boldsymbol{s}$: $\boldsymbol{s}^2 = \hbar^2 s(s+1)$ where $\hbar$ is the reduced Planck constant (ISO 80000-1)	1	Spin quantum numbers of fermions are odd multiples of 1/2, and those of bosons are integers.