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International Standard ISO 31/9

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Quantities and units of atomic and nuclear physics

Grandeurs et unités de physique atomique et nucléaire

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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 31/9 was developed by Technical Committee ISO/TC 12, *Quantities, units, symbols, conversion factors and conversion tables*, and was circulated to the member bodies in July 1979.

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

Australia	France	Portugal
Austria	Germany, F.R.	Romania
Belgium	India	South Africa, Rep. of
Brazil	Israel	Spain
Bulgaria	Italy	Sweden
Canada	Japan	Switzerland
Cuba	Mexico	United Kingdom
Czechoslovakia	Netherlands	USA
Denmark	New Zealand	USSR
Egypt, Arab Rep. of	Norway	
Finland	Poland	

No member body expressed disapproval of the document.

This second edition cancels and replaces the first edition (i.e. ISO 31/9-1973).

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Quantities and units of atomic and nuclear physics

Introduction

This document, containing a table of *quantities and units of atomic and nuclear physics*, is part 9 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 principles concerning quantities, units and symbols.*

Part 1 : *Quantities and units of space and time.*

Part 2 : *Quantities and units of periodic and related phenomena.*

Part 3 : *Quantities and units of mechanics.*

Part 4 : *Quantities and units of heat.*

Part 5 : *Quantities and units of electricity and magnetism.*

Part 6 : *Quantities and units of light and related electromagnetic radiations.*

Part 7 : *Quantities and units of acoustics.*

Part 8 : *Quantities and units of physical chemistry and molecular physics.*

Part 9 : *Quantities and units of atomic and nuclear physics.*

Part 10 : *Quantities and units of nuclear reactions and ionizing radiations.*

Part 11 : *Mathematical signs and symbols for use in the physical sciences and technology.*

Part 12 : *Dimensionless parameters.*

Part 13 : *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 pages.

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. When a preferred symbol and a reserve symbol are given, the reserve symbol is in parentheses.

Tables of units

Units for the corresponding quantities are given together with the international symbols and the definitions. For further information, see also ISO 31/0.

(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.

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 explicity 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. These annexes are not integral parts of the standards. They are arranged in three groups :

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

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

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

3) *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 of 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 plane angle and solid angle are to be considered as base quantities or derived quantities.[1]

In ISO 31, plane angle and solid angle are treated as derived quantities (see also ISO 31/0). In ISO 31, they are defined as ratios of two lengths and of 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[2]

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

The fundamental physical constants given in this document are either quoted in or calculated from the consistent values of the fundamental physical constants published in CODATA Bulletin 11, 1973.

For some of the "electrical" quantities, equations founded on three base quantities, in particular equations of the Gaussian system, are given in Annex D, together with the numerical values of certain atomic constants expressed in the units of the Gaussian CGS system. For further details, see the introduction to ISO 31/5.

The names and symbols of the chemical elements are given in annex A.

The names and symbols for nuclides of the radioactive series are given in annex C.

In this standard, annexes A and B are integral parts of the standard. Annexes C, D and E are not integral parts of the standard.

(1) However, in October 1980 the International Committee of Weights and Measures decided to interpret the class of supplementary units in the International System as a class of dimensionless derived units for which the General Conference of Weights and Measures leaves open the possibility of using these or not in expressions of derived units of the International System.

(2) 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.

Quantities
9-1.1 . . . 9-7.1

9. Atomic and nuclear physics

Item No.	Quantity	Symbol	Definition	Remarks
9-1.1	proton number, atomic number	Z	Number of protons in an atomic nucleus.	This quantity is dimensionless. A nuclide is a species of atoms with specified numbers of protons and neutrons. Nuclides with the same value of Z are called isotopes. The atomic number in the periodic table is equal to the proton number. See also annex B.
9-2.1	neutron number	N	Number of neutrons in an atomic nucleus.	This quantity is dimensionless. Nuclides with the same value of N are called isotones. $N - Z$ is called the neutron excess number.
9-3.1	nucleon number, mass number	A	Number of nucleons in an atomic nucleus.	This quantity is dimensionless. $A = Z + N$ Nuclides with the same value of A are called isobars. See also annex B.
9-4.1	mass of atom (of a nuclide X), nuclidic mass	m_a, $m(X)$	Rest mass of a neutral atom in the ground state.	For hydrogen ^1H $m(^1H) = (1{,}673\,559\,4 \pm 0{,}000\,008\,6) \times 10^{-27}$ kg $= (1{,}007\,825\,036 \pm 0{,}000\,000\,011)$ u
9-4.2	(unified) atomic mass constant	m_u	1/12 of the rest mass of a neutral atom of the nuclide ^{12}C in the ground state.	$m_u = (1{,}660\,565\,5 \pm 0{,}000\,008\,6) \times 10^{-27}$ kg $= 1$ u $\frac{m_a}{m_u}$ is called relative nuclidic mass.
				For a particle with rest mass m the quantity mc^2 is called its rest energy.
9-5.1	(rest) mass of electron	m_e		$m_e = (0{,}910\,953\,4 \pm 0{,}000\,004\,7) \times 10^{-30}$ kg $= (5{,}485\,802\,6 \pm 0{,}000\,002\,1) \times 10^{-4}$ u
9-5.2	(rest) mass of proton	m_p		$m_p = (1{,}672\,648\,5 \pm 0{,}000\,008\,6) \times 10^{-27}$ kg $= (1{,}007\,276\,470 \pm 0{,}000\,000\,011)$ u
9-5.3	(rest) mass of neutron	m_n		$m_n = (1{,}674\,954\,3 \pm 0{,}000\,008\,6) \times 10^{-27}$ kg $= (1{,}008\,665\,012 \pm 0{,}000\,000\,037)$ u
9-6.1	elementary charge	e	The electric charge of a proton.	The electric charge of an electron is equal to $(-e)$. $e = (1{,}602\,189\,2 \pm 0{,}000\,004\,6) \times 10^{-19}$ C
9-7.1	Planck constant	h	The elementary quantum of action.	$h = (6{,}626\,176 \pm 0{,}000\,036) \times 10^{-34}$ J.s $\hbar = h/2\pi$ $= (1{,}054\,588\,7 \pm 0{,}000\,005\,7) \times 10^{-34}$ J.s

9. Atomic and nuclear physics

Units
9-4.a . . . 9-7.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
9-4.a	kilogram	kg			
9-4.b	(unified) atomic mass unit	u	1 (unified) atomic mass unit is equal to 1/12 of the rest mass of a neutral atom of the nuclide ^{12}C in the ground state.	1 u = 1,660 565 5 × 10^{-27} kg	
9.5.a	kilogram	kg			
9-5.b	(unified) atomic mass unit	u		1 u = 1,660 565 5 × 10^{-27} kg	
9-6.a	coulomb	C			
9-7.a	joule second	J·s			

Quantities
9-8.1 . . . 9-16.1

9. Atomic and nuclear physics (continued)

Item No.	Quantity	Symbol	Definition	Remarks
9-8.1	Bohr radius	a_0	$a_0 = 4\pi\varepsilon_0\hbar^2/m_e e^2$	$a_0 = (0{,}529\ 177\ 06 \pm 0{,}000\ 000\ 44) \times 10^{-10}$ m
9-9.1	Rydberg constant	R_∞	$R_\infty = \dfrac{e^2}{8\pi\varepsilon_0 a_0 hc}$	$R_\infty = (1{,}097\,373\,177 \pm 0{,}000\,000\,083) \times 10^7$ m-1 For hydrogen [1]H $R_H = R_\infty/(1 + m_e/m_p)$ The quantity $R_\infty hc$ is called the Rydberg energy (R_y).
9-10.1 (—)	Hartree energy	E_h	$E_h = e^2/4\pi\varepsilon_0 a_0 = 2R_\infty \cdot hc$	$E_h = 4{,}359\ 81 \times 10^{-18}$ J
9-11.1 (9-10.1)	magnetic moment of particle or nucleus	μ	Expectation value of the component of the electromagnetic moment in the direction of the magnetic field in the quantum state with maximum magnetic quantum number.	The energy in a magnetic field with magnetic flux density B, in the quantum state with maximum magnetic quantum number, in vacuo, is equal to $-\mu B$.
9-11.2 (9-10.2)	Bohr magneton	μ_B	$\mu_B = e\hbar/2m_e$	$\mu_B = (9{,}274\ 078 \pm 0{,}000\ 036) \times 10^{-24}$ A.m2
9-11.3 (9-10.3)	nuclear magneton	μ_N	$\mu_N = e\hbar/2m_p = (m_e/m_p)\mu_B$	$\mu_N = (5{,}050\ 824 \pm 0{,}000\ 020) \times 10^{-27}$ A.m2
9-12.1 (9-11.1)	gyromagnetic coefficient, (gyromagnetic ratio)	γ	$\gamma = \mu/J\hbar$ where J is the angular momentum quantum number.	The gyromagnetic coefficient of the proton is indicated by γ_p. $\gamma_p = (2{,}675\ 198\ 7 \pm 0{,}000\ 007\ 5) \times 10^8$ A.m2/J.s.
9-13.1 (9-12.1)	g-factor of atom or electron	g	$\gamma = -g\dfrac{\mu_B}{\hbar} = -g\dfrac{e}{2m_e}$	These quantities are dimensionless. They are also called g-values.
9-13.2 (9-12.2)	g-factor of nucleus or nuclear particle	g	$\gamma = g\dfrac{\mu_N}{\hbar} = g\dfrac{e}{2m_p}$	
9-14.1 (9-13.1)	Larmor angular frequency, Larmor circular frequency	ω_L	$\omega_L = \dfrac{e}{2m_e}B$	$\nu_L = \omega_L/2\pi$ is called the Larmor frequency.
9-14.2 (9-13.2)	nuclear precession angular frequency, nuclear precession circular frequency	ω_N	$\omega_N = \gamma B$ where B is the magnetic flux density.	
9-15.1 (9-14.1)	cyclotron angular frequency, cyclotron circular frequency	ω_c	$\omega_c = \dfrac{q}{m}B$ where $\dfrac{q}{m}$ is the charge to mass ratio of the particle and B is the magnetic flux density.	$\nu_c = \omega_c/2\pi$ is called the cyclotron frequency.
9-16.1 (9-15.1)	nuclear quadrupole moment	Q	Expectation value of the quantity $(1/e)\int(3z^2 - r^2)\varrho(x,y,z)\,\mathrm{d}x\mathrm{d}y\mathrm{d}z$ in the quantum state with the nuclear spin in the field (z) direction; $\varrho(x,y,z)$ is the nuclear charge density, e is the elementary charge.	The electric nuclear quadropole moment is eQ.

9. Atomic and nuclear physics (continued)

Units
9-8.a . . . 9-16.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
9-8.a	metre	m			
9-8.b	ångström	Å	1 Å = 10^{-10} m	1 Å = 10^{-10} m (exactly)	10 Å = 1 nm
9-9.a	reciprocal metre, metre to the power minus one	m^{-1}			
9-10.a	joule	J			
9-11.a	ampere square metre	$A \cdot m^2$			
9-12.a	ampere square metre per joule second	$A \cdot m^2/(J \cdot s)$			$1\ A \cdot m^2/(J \cdot s) = 1\ C/kg = 1\ T^{-1} \cdot s^{-1}$
9-14.a	reciprocal second, second to the power minus one	s^{-1}			See the introduction.
9-14.b	radian per second	rad/s			
9-15.a	reciprocal second, second to the power minus one	s^{-1}			See the introduction.
9-15.b	radian per second	rad/s			
9-16.a	square metre	m^2			

Quantities
9-17.1 . . . 9-29.2

9. **Atomic and nuclear physics** (continued)

Item No.	Quantity	Symbol	Definition	Remarks
9-17.1 (9-16.1)	nuclear radius	R	The average radius of the volume in which the nuclear matter is included.	This quantity is not exactly defined. It is approximately given by $R = r_0 A^{1/3}$ where $r_0 \approx 1{,}2 \times 10^{-15}$ m.
9-18.1 (9-17.1)	orbital angular momemtum quantum number	l_i, L		This quantity is dimensionless. Usually l_i refers to a particle i; L is used for the whole system.
9-19.1 (9-18.1)	spin angular momentum quantum number	s_i, S		This quantity is dimensionless. Usually s_i refers to a particle i; S is used for the whole system.
9-20.1 (9-19.1)	total angular momentum quantum number	j_i, J		This quantity is dimensionless. Usually j_i refers to a particle i; J is used for the whole system.
9-21.1 (9-20.1)	nuclear spin quantum number	I		This quantity is dimensionless. In nuclear and particle physics J is often used.
9-22.1 (9-21.1)	hyperfine structure quantum number	F		This quantity is dimensionless.
9-23.1 (9-22.1)	principal quantum number	n		This quantity is dimensionless.
9-24.1 (9-23.1)	magnetic quantum number	m_i, M		This quantity is dimensionless. Usually m_i refers to a particle i; M is used for the whole system. Subscripts L, S, J, etc. as appropriate may be added to indicate the angular momentum involved.
9-25.1 (9-24.1)	fine-structure constant	α	$\alpha = e^2/4\pi\varepsilon_0\hbar c$	This quantity is dimensionless. $\alpha = (0{,}007\,297\,350\,6 \pm 0{,}000\,000\,006\,0)$ $1/\alpha = 137{,}036\,04 \pm 0{,}000\,11$
9-26.1 (9-25.1)	electron radius	r_e	$r_e = e^2/4\pi\varepsilon_0 m_e c^2$	$r_e = (2{,}817\,938\,0 \pm 0{,}000\,007\,0) \times 10^{-15}$ m.
9-27.1 (9-26.1)	Compton wavelength	λ_C	$\lambda_C = 2\pi\hbar/mc = h/mc$ where m is the rest mass of the particle.	For the proton, $\lambda_{C,p} = (1{,}321\,409\,9 \pm 0{,}000\,002\,2) \times 10^{-15}$ m. For the neutron, $\lambda_{C,n} = (1{,}319\,590\,9 \pm 0{,}000\,002\,2) \times 10^{-15}$ m.
9-28.1 (9-27.1)	mass excess	Δ	$\Delta = m_a - Am_u$	If the binding energy of the atomic electrons is neglected, Bc^2 is equal to the binding energy of the nucleus.
9-28.2 (9-27.2)	mass defect	B	$B = Zm(^1H) + Nm_n - m_a$	
9-29.1 (9-28.1)	relative mass excess	Δ_r	$\Delta_r = \Delta/m_u$	These quantities are dimensionless.
9-29.2 (9-28.2)	relative mass defect	B_r	$B_r = B/m_u$	

9. Atomic and nuclear physics (continued)

Units
9-17.a . . . 9-28.b

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
9-17.a	metre	m			The quantity 9-17.1 is usually expressed in femtometres. 1 fm = 10^{-15} m
9-26.a	metre	m			
9-27.a	metre	m			
9-28.a	kilogram	kg			
9-28.b	(unified) atomic mass unit	u		1 u = 1,660 565 5 × 10^{-27} kg	The quantities 9-28 are usually expressed in (unified) atomic mass units.

Quantities
9-30.1 . . . 9-40.1

9. Atomic and nuclear physics (concluded)

Item No.	Quantity	Symbol	Definition	Remarks
9-30.1 (9-29.1)	packing fraction	f	$f = \Delta_r/A$	These quantities are dimensionless.
9-30.2 (9-29.2)	binding fraction	b	$b = B_r/A$	
9-31.1 (9-30.1)	mean life	τ	For exponential decay, the average time required to reduce the number N of atoms or nuclei in a specified state to N/e.	
9-32.1 (9-31.1)	level width	Γ	$\Gamma = \frac{\hbar}{\tau}$	
9-33.1 (9-32.1)	activity	A	The average number of spontaneous nuclear transitions from a particular energy state occurring in an amount of a radionuclide in a small time interval divided by that interval.	$A = -\mathrm{d}N/\mathrm{d}t$ For exponential decay, $A = \lambda N$. Here λ is the decay constant, see 9-35.1.
9-34.1 (9-33.1)	specific activity in a sample	a	The activity divided by the total mass of the sample.	
9-35.1 (9-34.1)	decay constant, disintegration constant	λ	The decay constant is the probability of decay in a small time interval, divided by that interval.	For exponential decay, $\mathrm{d}N/\mathrm{d}t = -\lambda N$ where N is the number of radioactive atoms at time t, and $\lambda = 1/\tau$.
9-36.1 (9-35.1)	half-life	$T_{1/2}$	For exponential decay, the average time required for the decay of one half of the atoms of a sample of a radioactive nuclide.	$T_{1/2} = (\ln 2)/\lambda$ $= \tau \ln 2$
9-37.1 (9-36.1)	alpha disintegration energy	Q_α	The sum of the kinetic energy of the α particle produced in the disintegration process and the recoil energy of the product atom in the reference frame in which the emitting nucleus is at rest before its disintegration.	The ground state alpha disintegration energy, $Q_{\alpha,0}$, includes also the energy of possible gamma radiation.
9-38.1 (9-37.1)	maximum beta particle energy	E_β	The maximum energy of the energy spectrum in a beta disintegration process.	
9-39.1 (9-38.1)	beta disintegration energy	Q_β	The sum of the maximum beta particle energy E_β and the recoil energy of the produced atom in the reference frame in which the emitting nucleus is at rest before its disintegration.	For emitters of positive electrons, the energy for the production of an electron pair has to be added to the sum mentioned in the definition. The ground state beta-disintegration energy, $Q_{\beta,0}$, includes also the energy of possible gamma radiation.
9-40.1 (9-39.1)	internal conversion factor	α	The ratio of the number of internal conversion electrons to the number of gamma quanta emitted by the atom in a given transition.	This quantity is dimensionless. The quantity $\alpha/(\alpha + 1)$ is also used and may be called internal conversion fraction. Partial conversion factors referring to various electron shells K, L, ... are indicated as $\alpha_K, \alpha_L, \ldots$ α_K/α_L is called the K to L internal conversion ratio.