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Quantities and units of atomic and nuclear physics

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FOREWORD

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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.

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It was approved in November 1968 by the Member Bodies of the following countries :

Australia	Hungary	Romania
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No Member Body expressed disapproval of the document.

Quantities and units of atomic and nuclear physics

INTRODUCTION

General remarks

This document, containing a table of *quantities and units of atomic and nuclear physics*, is the ninth part of a more comprehensive publication dealing with quantities and units in various fields of science and technology. The parts of this publication are :

Part 0 : *General introduction — General principles concerning quantities, units and symbols.*¹⁾

Part I (2nd edition) : *Basic quantities and units of the SI and quantities and units of space and time.*²⁾

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.*

General information regarding the arrangement of the tables and the symbols and abbreviations used is to be found in the introduction to Part I, where the full definitions of base units are given as an appendix.

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

Special remarks

For reasons of brevity, only (rationalized) equations founded on four base quantities to be used in connection with a unit system founded on four base units have been included in the tables.

As the units of the CGS system are widely used in the field of atomic and nuclear physics, the CGS units for some of the "mechanical" quantities are given in addition to those of the International System of Units.

For some of the "electrical" quantities, equations founded on three base quantities, in particular equations of the (non-rationalized) symmetric system, are given in Appendix I, together with the numerical values of certain atomic constants expressed in the units of the symmetric CGS system.

For further details, see the introduction to Part V.

The names and symbols for the chemical elements are given in Appendix III.

The names and symbols for the nuclides of the radioactive series are given in Appendix IV.

1) At present at the stage of draft (No. 2180).

2) 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".

9. Atomic and nuclear physics

Item No.	Quantity	Symbol	Definition 1)	Remarks 2)
9-1.1	proton number, atomic number	Z	Number of protons in a nucleus, number of electrons in a neutral atom.	This quantity is dimensionless. A nuclide is a species of neutral atoms with specified number of protons and neutrons. Nuclides with the same value of Z are called isotopes. See also Appendix II.
9-2.1	neutron number	N	Number of neutrons in a 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 a nucleus.	This quantity is dimensionless. $A = Z + N$. Nuclides with the same value of A are called isobars. See also Appendix II.
9-4.1	mass of atom (of a nuclide X), nuclidic mass	$m_a, m(X)$	Rest mass of an atom.	For hydrogen ${}^1\text{H}$: $m({}^1\text{H}) = (1.673\,43 \pm 0.000\,08) \times 10^{-27} \text{ kg}$ $= (1.673\,43 \pm 0.000\,08) \times 10^{-24} \text{ g}$ $= (1.007\,825\,22 \pm 0.000\,000\,24) \text{ u}$
9-4.2	(unified) atomic mass constant	m_u	$1/12$ of the rest mass of an atom of nuclide ${}^{12}\text{C}$.	$m_u = (1.660\,44 \pm 0.000\,08) \times 10^{-27} \text{ kg}$ $= (1.660\,44 \pm 0.000\,08) \times 10^{-24} \text{ g}$ $= 1 \text{ u}$ $\frac{m_a}{m_u}$ is called relative nuclidic mass.
9-5.1	(rest) mass of electron	m_e		For a particle with rest mass m the quantity mc^2 is called its rest energy. $m_e = (9.1091 \pm 0.0004) \times 10^{-31} \text{ kg}$ $= (9.1091 \pm 0.0004) \times 10^{-28} \text{ g}$ $= (5.485\,97 \pm 0.000\,09) \times 10^{-4} \text{ u}$
9-5.2	(rest) mass of proton	m_p		
9-5.3	(rest) mass of neutron	m_n		
9-6.1	elementary charge	e	The electric charge of a proton.	The magnitude of the electric charge of an electron is equal to e . $e = (1.602\,10 \pm 0.000\,07) \times 10^{-19} \text{ C}$ See also Appendix I.
9-7.1	Planck constant	h	The elementary quantum of action.	$h = (6.6256 \pm 0.0005) \times 10^{-34} \text{ J} \cdot \text{s}$ $= (6.6256 \pm 0.0005) \times 10^{-27} \text{ erg} \cdot \text{s}$ $\hbar = h/2\pi$
9-8.1	Bohr radius	a_0	$a_0 = 4\pi\epsilon_0 \hbar^2 / m_e e^2$	$a_0 = (5.291\,67 \pm 0.000\,07) \times 10^{-11} \text{ m}$ $= (5.291\,67 \pm 0.000\,07) \times 10^{-9} \text{ cm}$ $= (5.291\,67 \pm 0.000\,07) \times 10^{-1} \text{ \AA}$ See also Appendix I.

1) The statements in this column are given merely for identification and they are not intended to be complete definitions.
2) The numerical values in this column are derived from J. W. M. DuMond and E. R. Cohen, Recommended Values of the Physical Constants - 1963 I.U.P.A.P. Commission on Nuclidic Masses, Doc. MN 632 - Sept. 4, 1963. See also NBS Technical News Bulletin 47, 175 (1963).

9. Atomic and nuclear physics

Units
9-4.a...9-8.c

Item No.	Name of unit and in certain cases abbreviation for this name	International symbol for unit	Definition	Conversion factors	Remarks
9-4.a	kilogramme	kg			
9-4.b	gramme	g			
9-4.c	(unified) atomic mass unit	u	1 (unified) atomic mass unit is equal to $1/12$ of the mass of an atom of nuclide ^{12}C .	$1 \text{ u} = 1.66044 \times 10^{-27} \text{ kg}$ $= 1.66044 \times 10^{-24} \text{ g}$	
9-5.a	kilogramme	kg			
9-5.b	gramme	g			
9-5.c	(unified) atomic mass unit	u		$1 \text{ u} = 1.66044 \times 10^{-27} \text{ kg}$ $= 1.66044 \times 10^{-24} \text{ g}$	
9-6.a	coulomb	C			
9-7.a	joule second	J·s			
9-7.b	erg second	erg·s		$1 \text{ erg} \cdot \text{s} = 10^{-7} \text{ J} \cdot \text{s}$ (exactly)	
9-8.a	metre	m			
9-8.b	centimetre	cm			
9-8.c	ångström	Å	$1 \text{ Å} = 10^{-10} \text{ m}$	$1 \text{ Å} = 10^{-10} \text{ m}$ (exactly)	

Item No.	Quantity	Symbol	Definition 1)	Remarks 2)
9-9.1	Rydberg constant	R_{∞}	$R_{\infty} = \frac{e^2}{8\pi\epsilon_0 a_0 hc}$	$R_{\infty} = (1.097\,373\,1 \pm 0.000\,000\,3) \times 10^7 \text{ m}^{-1}$ $= (1.097\,373\,1 \pm 0.000\,000\,3) \times 10^5 \text{ cm}^{-1}$ $R_{\infty} \cdot c = (3.289\,842 \pm 0.000\,003) \times 10^{15} \text{ s}^{-1}$ $R_{\infty} \cdot h \cdot c = (2.179\,72 \pm 0.000\,17) \times 10^{-18} \text{ J}$ $= (2.179\,72 \pm 0.000\,17) \times 10^{-11} \text{ erg}$ $= (13.6054 \pm 0.000\,1) \text{ eV}$ <p>This quantity is also called the rydberg (Ry).</p> <p>For hydrogen ^1H: $R_{\text{H}} = R_{\infty} / (1 + m_e/m_p)$ See also Appendix I.</p>
9-10.1	magnetic moment of particle or nucleus	μ	The maximum expectation value of the component of the electromagnetic moment in the direction of the magnetic field.	The maximum energy in a magnetic field with magnetic flux density B in vacuo is $\mu \cdot B$
9-10.2	Bohr magneton	μ_{B}	$\mu_{\text{B}} = e\hbar/2m_e$	$\mu_{\text{B}} = (9.2732 \pm 0.0006) \times 10^{-24} \text{ A} \cdot \text{m}^2$ See also Appendix I.
9-10.3	nuclear magneton	μ_{N}	$\mu_{\text{N}} = e\hbar/2m_p = (m_e/m_p)\mu_{\text{B}}$	$\mu_{\text{N}} = (5.0505 \pm 0.0004) \times 10^{-27} \text{ A} \cdot \text{m}^2$ See also Appendix I.
9-11.1	gyromagnetic ratio, gyromagnetic coefficient	γ	$\gamma = \mu/I\hbar$ where I is the particle spin quantum number. The quotient of the maximum expectation values of the components of the electromagnetic moment and the angular momentum in the direction of the magnetic field.	The gyromagnetic ratio of the proton is indicated by γ_{p} $\gamma_{\text{p}} = (2.675\,19 \pm 0.000\,02) \times 10^8 \text{ A} \cdot \text{m}^2 / (\text{J} \cdot \text{s})$
9-12.1	g-factor of atom or electron	g	$\gamma = g \frac{\mu_{\text{B}}}{\hbar} = g \frac{e}{2m_e}$	These quantities are dimensionless.
9-12.2	g-factor of nucleus	g	$\gamma = g \frac{\mu_{\text{N}}}{\hbar} = g \frac{e}{2m_p}$	Also called g-value. See also Appendix I.
9-13.1	Larmor angular frequency	ω_{L}	$\omega_{\text{L}} = \frac{e}{2m_e} B$	See also Appendix I.
9-13.2	nuclear angular precession frequency	ω_{N}	$\omega_{\text{N}} = g \frac{e}{2m_p} B$ where B is the magnetic flux density.	
9-14.1	cyclotron angular frequency	ω_{c}	$\omega_{\text{c}} = \frac{q}{m} \cdot B$ where $\frac{q}{m}$ is the charge to mass ratio of the particle and B is the magnetic flux density.	See also Appendix I.
9-15.1	nuclear quadrupole moment	Q	Expectation value of the quantity $(1/e) \int (3z^2 - r^2) \rho(x, y, z) dx dy dz$ In the quantum state with the nuclear spin in the field direction; $\rho(x, y, z)$ is the nuclear charge density, e is the elementary charge.	

1) See footnote 1 on page 2.
2) See footnote 2 on page 2.

Item No.	Name of unit and in certain cases abbreviation for this name	International symbol for unit	Definition	Conversion factors	Remarks
9-9.a	reciprocal metre	m ⁻¹			
9-9.b	reciprocal centimetre	cm ⁻¹			
9-10.a	ampere square metre	A · m ²			
9-11.a	ampere square metre per joule second	A · m ² /(J · s)			1 A · m ² /(J · s) = 1 C/kg = 1 T ⁻¹ · s ⁻¹
9-13.a	reciprocal second	s ⁻¹			
9-14.a	reciprocal second	s ⁻¹			
9-15.a	square metre	m ²			
9-15.b	square centimetre	cm ²			

Item No.	Quantity	Symbol	Definition 1)	Remarks 2)
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
9-17.1	orbital angular momentum quantum number	l_i, L		This quantity is dimensionless. Usually l_i refers to a particle i ; L is used for the whole system.
9-18.1	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.
9-19.1	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.
9-20.1	nuclear spin quantum number	I		This quantity is dimensionless. In nuclear spectroscopy J is often used.
9-21.1	hyperfine structure quantum number	F		This quantity is dimensionless.
9-22.1	principal quantum number	n		This quantity is dimensionless.
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.
9-24.1	fine-structure constant	α	$\alpha = e^2/4\pi\epsilon_0\hbar c$	This quantity is dimensionless. $\alpha = 1/(137.0388 \pm 0.0019)$ $= (7.297\ 20 \pm 0.000\ 10) \times 10^{-3}$ See also Appendix I.
9-25.1	electron radius	r_e	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	$r_e = (2.817\ 77 \pm 0.000\ 11) \times 10^{-15}$ m $= (2.817\ 77 \pm 0.000\ 11) \times 10^{-13}$ cm See also Appendix I.
9-26.1	Compton wave-length	λ_C	$\lambda_C = 2\pi\hbar/mc = h/mc$ where m is the rest mass of the particle.	
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.
9-27.2	mass defect	B	$B = Zm(^1\text{H}) + Nm_n - m_a$	
9-28.1	relative mass excess	Δ_r	$\Delta_r = \Delta/m_u$	These quantities are dimensionless.
9-28.2	relative mass defect	B_r	$B_r = B/m_u$	
9-29.1	packing fraction	f	$f = \Delta_r/A$	These quantities are dimensionless.
9-29.2	binding fraction	b	$b = B_r/A$	

1) See footnote 1 on page 2.

2) See footnote 2 on page 2.

9. Atomic and nuclear physics (continued)

Units
9-16.a...9-27.c

Item No.	Name of unit and in certain cases abbreviation for this name	International symbol for unit	Definition	Conversion factors	Remarks
9-16.a	metre	m			The quantity 9-16.1 is usually expressed in femtometre. $1 \text{ fm} = 10^{-15} \text{ m}$
9-16.b	centimetre	cm			
9-25.a	metre	m			
9-25.b	centimetre	cm			
9-26.a	metre	m			
9-26.b	centimetre	cm			
9-27.a	kilogramme	kg			
9-27.b	gramme	g			
9-27.c	(unified) atomic mass unit	u		$1 \text{ u} = 1.66044 \times 10^{-27} \text{ kg}$ $= 1.66044 \times 10^{-24} \text{ g}$	The quantities 9-27 are usually expressed in (unified) atomic mass units.

Item No.	Quantity	Symbol	Definition 1)	Remarks
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 .	
9-31.1	level width	Γ	$\Gamma = \frac{\hbar}{\tau}$	
9-32.1	activity	A	The number of nuclear transformations or transitions occurring in a certain amount of a radionuclide or in a radioactive source in a small time interval divided by that interval.	Values given for activities are not always unambiguous unless the radionuclide or the radioactive source and the type of transformation or transition are specified. For exponential decay of a nuclide, $A = -dN/dt = \lambda N$ See 9-34.1
9-33.1	specific activity of a sample	a	The activity of a radioactive nuclide present in a sample divided by the total mass of the sample.	
9-34.1	decay constant, disintegration constant	λ	For exponential decay, $dN/dt = -\lambda N$ where N is the number of radioactive atoms at time t .	$\lambda = \frac{1}{\tau}$
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.	$T_{1/2} = (\ln 2)/\lambda$ $= \tau \ln 2$
9-36.1	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.
9-37.1	beta maximum energy	E_{β}	The maximum energy of the energy spectrum in a beta-disintegration process.	
9-38.1	beta-disintegration energy	Q_{β}	The sum of the beta maximum 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 positron emitters 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.
9-39.1	internal conversion coefficient, internal conversion factor	α	The ratio of the number of internal conversion electrons to the number of gamma quanta emitted by the atom in the de-excitation of a nucleus.	This quantity is dimensionless. The quantity $\alpha/(\alpha + 1)$ is also used and may be called internal conversion fraction. Partial conversion coefficients referring to various electron shells K, L, ... are indicated as $\alpha_K, \alpha_L, \dots$ α_K/α_L is called the K to L internal conversion ratio.

1) See footnote 1 on page 2.

9. Atomic and nuclear physics (end)

Units
9-30.a...9-38.c

Item No.	Name of unit and in certain cases abbreviation for this name	International symbol for unit	Definition	Conversion factors	Remarks
9-30.a	second	s			
9-31.a	joule	J			
9-31.b	erg	erg		1 erg = 10^{-7} J (exactly)	
9-31.c	electronvolt	eV		1 eV = $1.602\ 10 \times 10^{-19}$ J	
9-32.a	reciprocal second	s ⁻¹			
9-32.b	curie	Ci	1 Ci = 3.7×10^{10} s ⁻¹	1 Ci = 3.7×10^{10} s ⁻¹ (exactly)	
9-33.a	reciprocal second reciprocal kilogramme	s ⁻¹ · kg ⁻¹			
9-33.b	reciprocal second reciprocal gramme	s ⁻¹ · g ⁻¹			
9-33.c	curie per gramme	Ci/g			
9-34.a	reciprocal second	s ⁻¹			
9-35.a	second	s			
9-36.a	joule	J			
9-36.b	erg	erg			
9-36.c	electronvolt	eV		1 eV = $1.602\ 10 \times 10^{-19}$ J	The quantity 9-36.1 is usually expressed in electronvolts.
9-37.a	joule	J			
9-37.b	erg	erg			
9-37.c	electronvolt	eV		1 eV = $1.602\ 10 \times 10^{-19}$ J	The quantity 9-37.1 is usually expressed in electronvolts.
9-38.a	joule	J			
9-38.b	erg	erg			
9-38.c	electronvolt	eV		1 eV = $1.602\ 10 \times 10^{-19}$ J	The quantity 9-38.1 is usually expressed in electronvolts.

Appendix I ¹⁾

Examples of relations in different systems of equations

Item No.	Subject	Rationalized system of equations with four basic quantities	Non-rationalized symmetric system of equations with three basic quantities
1	Bohr radius	$a_0 = 4\pi\epsilon_0\hbar^2/m_e e^2$	$a_0 = \hbar^2/m_e e_s^2$
2	Rydberg constant	$R_\infty = m_e e^4/(4\pi)^2 \epsilon_0^2 \hbar^3 c$	$R_\infty = m_e e_s^4/4\pi \hbar^3 c$
3	Bohr magneton	$\mu_B = e\hbar/2m_e$	$\mu_{Bs} = e_s \hbar/2m_e c$
4	nuclear magneton	$\mu_N = e \hbar/2m_p$	$\mu_{Ns} = e_s \hbar/2m_p c$
5	relation between gyromagnetic ratio and g-factor of nucleus	$\gamma = g \mu_N/\hbar = g e/2m_p$	$\gamma_s = g \mu_{Ns}/\hbar = g e_s/2m_p c$
6	Larmor angular frequency	$\omega_L = (e/2m_e) B$	$\omega_{Ls} = (e_s/2m_e c) B_s$
7	cyclotron angular frequency (of electron)	$\omega_c = (e/m_e) B$	$\omega_{cs} = (e_s/m_e c) B_s$
8	fine-structure constant	$\alpha = e^2/4\pi\epsilon_0 \hbar c$	$\alpha = e_s^2/\hbar c$
9	electron radius	$r_e = e^2/4\pi\epsilon_0 m_e c^2$	$r_{es} = e_s^2/m_e c^2$
10	Compton wavelength	$\lambda_C = h/mc = 2\pi\hbar/mc$	$\lambda_{Cs} = h/mc = 2\pi\hbar/mc$

1) Quantities occurring in the second column of equations which differ from the corresponding quantity in the first column of equations are provided with a suffix *s* (symmetric). The values of some of the quantities expressed in units of the "symmetric" CGS system (see Introduction to ISO/R 31/Part V) are as follows:

$e_s = (4.802\ 98 \pm 0.000\ 20) \times 10^{-10}$ electrostatic CGS unit of charge

$\mu_{Bs} = (9.2732 \pm 0.0006) \times 10^{-21}$ erg per gauss

$\mu_{Ns} = (5.0505 \pm 0.0004) \times 10^{-24}$ erg per gauss

$\gamma_{ps} = (2.675\ 19 \pm 0.000\ 02) \times 10^4$ reciprocal second reciprocal gauss, where γ_{ps} is the gyromagnetic ratio γ_s of the proton.

Appendix II

Symbols for Chemical Elements and Nuclides

Symbols for chemical elements should be written in roman (upright) type. The symbol is not followed by a full stop.

Examples: H He Ca C

The attached numerals specifying a nuclide or molecule should have the following meaning:

nucleon number $^{14}\text{N}_2$ atoms per molecule

The proton number (atomic number) may be indicated in the left subscript position.

The right superscript position should be reserved to indicate if necessary a state of ionization or an excited state.

Examples:

State of ionization: Na^+ , PO_4^{3-}

Electronic excited state: He^* , NO^*

Nuclear excited state: $^{110}\text{Ag}^*$ or $^{110}\text{Ag}^m$