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Quantities and units - Part 10: Atomic and nuclear physics

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Saudi Standards, Metrology and Quality Org (SASO)

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this document is a draft saudi standard circulated for comment. it is, therefore subject to change and may not be referred to as a saudi standard until approved by the board of directors.

Foreword

The Saudi Standards ,Metrology and Quality Organization (SASO)has adopted the International standard No. ISO 80000-10:2019 “Quantities and units — Part 10: Atomic and nuclear physics” issued by (ISO). The text of this international standard has been translated into Arabic so as to be approved as a Saudi standard.

Contents

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: $E_0 = m_0 c_0^2$	J N m kg m^2 s^{-2}	

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			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)		
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-}.

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: $a_0 = \frac{4\pi\varepsilon_0\hbar^2}{m_\mathrm{e}e^2}$ 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.
10-8	Hartree energy	E_H E_h	energy (ISO 80000-5) of the electron in a hydrogen atom in its ground state: $E_\mathrm{H} = \frac{e^2}{4\pi\varepsilon_0 a_0}$ 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 $\mathrm{kg\ m^2\ s^{-2}}$	The energy of the electron in an H atom in its ground state is E_H.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
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	
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).

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
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 $\hbar$.
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}

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 $\lvert \Psi \rvert^2$, 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 $E_n = E_{\mathrm{H}}/n^2$.
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	$\lvert \boldsymbol{l} \rvert^2 = \hbar^2 l(l-1)$, $l=0,1,\ldots,n-1$ where

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					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), ***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.
10-13.6	total angular momentum quantum number	j j_i J	quantum number in an atom describing the magnitude of total angular momentum ***J*** (item 10-11)	1	j_i refers to a specific particle *i*; *J* is used for the whole system. The quantum number *J* and the magnitude of total angular momentum ***J*** (item 10-11) are different quantities. The two values of *j* are *l*±1/2. (See item 10-13.3.)

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-13.7	nuclear spin quantum number	I	quantum number related to the total angular momentum (item 10-11), $\boldsymbol{J}$, of a nucleus in any specified state, normally called nuclear spin: $\boldsymbol{J}^2 = \hbar^2 I(I+1)$ where $\hbar$ is the reduced Planck constant (ISO 80000-1)	1	Nuclear spin is composed of spins of the nucleons (protons and neutrons) and their (orbital) motions. In principle there is no upper limit for the nuclear spin quantum number. It has possible values I = 0,1,2,... for even A and $I = \frac{1}{2}, \frac{3}{2}, \ldots$ for odd A. In nuclear and particle physics, $\boldsymbol{J}$ is often used.
10-13.8	hyperfine structure quantum number	F	quantum number of an atom describing the inclination of the nuclear spin with respect to a quantization axis given by the magnetic field produced by the orbital electrons	1	The interval of F is $\lvert I-J \rvert$, $\lvert I-J \rvert+1$, ..., $I-J$. This is related to the hyperfine splitting of the atomic energy levels due to the interaction between the electron and nuclear magnetic moments.
10-14.1	Landé factor, g factor of atom	g	quotient of the magnetic dipole moment of an atom, and the product of the total angular momentum quantum number and the Bohr magneton: $g = \frac{\mu}{J \cdot \mu_B}$ where μ is magnitude of magnetic dipole moment (item 10-9.1), J is total angular momentum quantum number (item 10-13.6), and μ_B is the Bohr magneton (item 10-9.2)	1	These quantities are also called g values. The Landé factor can be calculated from the expression: $g(L,S,J) = 1 + (g_e - 1) \times \frac{J(J+1)+S(S+1)-L(L+1)}{2J(J+1)}$ where g_e is the g factor of the electron.
10-14.2	g factor of nucleus or nuclear particle	g	quotient of the magnetic dipole moment of an atom, and the product of the nuclear spin quantum number and the nuclear magneton:	1	The g factors for nuclei or nucleons are known from measurements.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			$g = \frac{\mu}{I \cdot \mu_N}$ where μ is magnitude of magnetic dipole moment (item 10-9.1), I is nuclear spin quantum number (item 10-13.7), and μ_N is the nuclear magneton (item 10-9.3)		
10-15.1	Larmor angular frequency	ω_L	angular frequency (ISO 80000-3) of the electron angular momentum (ISO 80000-4) vector precession about the axis of an external magnetic field: $\omega_L = \frac{e}{2m_e} B$ where e is the elementary charge (ISO 80000-1), m_e is the rest mass (item 10-2) of electron, and B is magnetic flux density (IEC 80000-6)	rad s^{-1} s^{-1}	
10-15.2	Larmor frequency	ν_L	quotient of Larmor angular frequency (ISO 80000-3) and 2π	s^{-1}	
10-15.3	nuclear precession angular frequency	ω_N	frequency (ISO 80000-3) by which the nucleus angular momentum vector (ISO 80000-4) precesses about the axis of an external magnetic field: $\omega_N = \gamma B$ where γ is the gyromagnetic ratio (item 10-12.1), and B is magnetic flux density (IEC 80000-6)	rad s^{-1} s^{-1}	
10-16	cyclotron angular frequency	ω_c	quotient of the product of the electric charge of a particle and the magnitude of the magnetic flux density of the magnetic field, and the particle mass: $\omega_c = \frac{\lvert q \rvert}{m} B$	rad s^{-1} s^{-1}	The quantity $\nu_c = \omega_c / 2\pi$ is called the cyclotron frequency.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			where q is the electric charge (IEC 80000-6) of the particle, m is the mass (ISO 80000-4) of the particle, and B is the absolute value of the magnetic flux density (IEC 80000-6)		
10-17	gyroradius, Larmor radius	r_g r_L	radius (ISO 80000-3) of circular movement of a particle with mass (ISO 80000-4), velocity $\boldsymbol{v}$ (ISO 80000-3), and electric charge q (IEC 80000-6), moving in a magnetic field with magnetic flux density $\boldsymbol{B}$ (IEC 80000-6): $r_\mathrm{g} = \dfrac{m\lvert \boldsymbol{v} \times \boldsymbol{B} \rvert}{qB^2}$	m	
10-18	nuclear quadrupole moment	Q	z component of the diagonalized tensor of nuclear quadrupole moment: $Q = \left(1/e\right) \int (3z^2 - r^2) \rho(x, y, z) \, \mathrm{d}V$ in the quantum state with the nuclear spin in the field direction (z), where e is the elementary charge (ISO 80000-1), $r^2 = x^2 + y^2 + z^2$, $\rho(x,y,z)$ is the nuclear electric charge density (IEC 80000-6), and $\mathrm{d}V$ is the volume element $\mathrm{d}x\,\mathrm{d}y\,\mathrm{d}z$	m^2	The electric nuclear quadrupole moment is eQ. This value is equal to the z component of the diagonalized tensor of quadrupole moment.
10-19.1	nuclear radius	R	conventional radius (ISO 80000-3) of sphere in which the nuclear matter is included	m	This quantity is not exactly defined. It is given approximately for nuclei in their ground state by: $R = r_0 A^{1/3}$ where $r_0 \approx 1{,}2 \times 10^{-15}$ m, and A is the nucleon number (item 10-1.3).

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					Nuclear radius is usually expressed in femtometres, 1 fm = 10^{-15} m.
10-19.2	electron radius	r_e	radius of a sphere such that the relativistic electron energy is distributed uniformly: $r_e = \frac{e^2}{4\pi\varepsilon_0 m_e c_0^2}$ where e is the elementary charge (ISO 80000-1), ε_0 is the electric constant (IEC 80000-6), m_e is the rest mass (item 10-2) of electron, and c_0 is the speed of light in vacuum (ISO 80000-1)	m	This quantity corresponds to the electrostatic energy E of a charge distributed inside a sphere of radius r_e as if all the rest energy (item 10-3) of the electron were attributed to the energy of electromagnetic origin, using the relation $E = m_e c_0^2$.
10-20	Compton wavelength	λ_C	quotient of the Planck constant and the product of the mass of the particle and the speed of light in vacuum: $\lambda_C = \frac{h}{mc_0}$ where h is the Planck constant (ISO 80000-1), m is the rest mass (item 10-2) of a particle, and c_0 is the speed of light in vacuum (ISO 80000-1)	m	The wavelength of electromagnetic radiation scattered from free electrons (Compton scattering) is larger than that of the incident radiation by a maximum of $2\lambda_C$.
10-21.1	mass excess	Δ	difference between the mass of an atom, and the product of its mass number and the unified mass constant: $\Delta = m_a - A \cdot m_u$ where m_a is the rest mass (item 10-2) of the atom, A is its nucleon number (item 10-1.3), and m_u is the unified atomic mass constant (item 10-4.3)	kg Da u	The mass excess is usually expressed in daltons, 1 Da = 1 u. See item 10-2.

Item No.	Quantity			Unit	Remarks
	Name	**Symbol**	**Definition**		
10-21.2	mass defect	B	sum of the product of the proton number and the hydrogen atomic mass, and the neutron rest mass, minus the rest mass of the atom: $B = Z\,m(^1\mathrm{H}) + N\,m_\mathrm{n} - m_\mathrm{a}$ where Z is the proton number (item 10-1.1) of the atom, $m(^1\mathrm{H})$ is atomic mass (item 10-4.1) of $^1\mathrm{H}$, N is neutron number (item 10-1.2), m_n is the rest mass (item 10-2) of the neutron, and m_a is the rest mass (item 10-2) of the atom	kg Da u	The mass excess is usually expressed in daltons, 1 Da = 1 u. If the binding energy of the orbital electrons is neglected, Bc_0^2 is equal to the binding energy of the nucleus.
10-22.1	relative mass excess	Δ_r	quotient of mass excess and the unified atomic mass constant: $\Delta_\mathrm{r} = \Delta / m_\mathrm{u}$ where Δ is mass excess (item 10-21.1), and m_u is the unified atomic mass constant (item 10-4.3)	1	
10-22.2	relative mass defect	B_r	quotient of mass defect and the unified atomic mass constant: $B_\mathrm{r} = B / m_\mathrm{u}$ where B is mass defect (item 10-21.2), and m_u is the unified atomic mass constant (item 10-4.3)	1	
10-23.1	packing fraction	f	quotient of relative mass excess and the nucleon number: $f = \Delta_\mathrm{r} / A$ where Δ_r is relative mass excess (item 10-22.1), and A is the nucleon number (item 10-1.3)	1	
10-23.2	binding fraction	b	quotient of relative mass defect and the nucleon number: $b = B_\mathrm{r} / A$ where	1	

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			B_r is relative mass defect (item 10-22.2), and A is the nucleon number (item 10-1.3)		
10-24	decay constant, disintegration constant	λ	quotient of $-\mathrm{d}N/N$ and $\mathrm{d}t$, where $\mathrm{d}N/N$ is the mean fractional change in the number of nuclei in a particular energy state due to spontaneous transformations in a time interval of duration (ISO 80000-3) $\mathrm{d}t$: $\lambda = -\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}t}$	s^{-1}	For exponential decay, this quantity is constant. For more than one decay channel, $\lambda = \sum \lambda_a$ where λ_a denotes the decay constant for a specified final state and the sum is taken over all final states.
10-25	mean duration of life, mean life time <atomic and nuclear physics>	τ	reciprocal of the decay constant λ (item 10-24): $\tau = \frac{1}{\lambda}$	s	Mean duration of life is the expected value of the duration of life of an unstable particle or an excited state of a particle when the number of decay events in a short time interval follows a Poisson distribution.
10-26	level width	Γ	quotient of the reduced Planck constant and the mean life: $\Gamma = \frac{\hbar}{\tau}$ where $\hbar$ is the reduced Planck constant (ISO 80000-1), and τ is mean duration of life (item 10-25)	eV J $\mathrm{kg\ m^2\ s^{-2}}$	Level width is the uncertainty of the energy of an unstable particle or an excited state of a system due to the Heisenberg principle. The term energy level refers to the configuration of the distribution function of the density of states. Energy levels may be considered as discrete, like those in an atom, or may have a finite width, like e.g. this item or like e.g. the valence or conduction band in solid state physics. Energy levels are applicable to both real and virtual particles, e.g. electrons and phonons, respectively.
10-27	activity	A	differential quotient of N with respect to time, where N is the mean change in the number of nuclei in a particular energy state due to spontaneous nuclear transformations in a time interval of duration (ISO 80000-3) $\mathrm{d}t$: $A = -\frac{\mathrm{d}N}{\mathrm{d}t}$	Bq s^{-1}	For exponential decay, $A = \lambda N$, where λ is the decay constant (item 10-24). The becquerel (Bq) is a special name for second to the power minus one, to be used as the coherent SI unit of activity.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					In report 85a of the ICRU a definition with an equivalent meaning is given as: The activity, A, of an amount of a radionuclide in a particular energy state at a given time is the quotient of -dN by dt, where dN is the mean change in the number of nuclei in that energy state due to spontaneous nuclear transformations in the time interval dt: $A = -\frac{\mathrm{d}N}{\mathrm{d}t}$. See also section 0.3.
10-28	specific activity, massic activity	a	quotient of the activity A (item 10-27) of a sample and the mass m (ISO 80000-4) of that sample: $a = A/m$	Bq/kg kg^{-1} s^{-1}	
10-29	activity density, volumic activity, activity concentration	c_A	quotient of the activity A (item 10-27) of a sample and the volume V (ISO 80000-3) of that sample: $c_A = A/V$	Bq/m^3 m^{-3} s^{-1}	
10-30	surface-activity density	a_S	quotient of the activity A (item 10-27) of a sample and the total area S (ISO 80000-3) of the surface of that sample: $a_S = A/S$	Bq/m^2 m^{-2} s^{-1}	This value is usually defined for flat sources, where S corresponds to the total area of surface of one side of the source.
10-31	half life	$T_{1/2}$	mean duration (ISO 80000-3) required for the decay of one half of the atoms or nuclei	s	For exponential decay, $T_{1/2} = (\ln 2)/\lambda$, where λ is the decay constant (item 10-24).
10-32	alpha disintegration energy	Q_α	sum of the kinetic energy (ISO 80000-4) of the α-particle produced in the disintegration process and the recoil energy (ISO 80000-5) of the product atom in a reference frame in which the emitting nucleus is at rest before its disintegration	eV J kg m^2 s^{-2}	The ground-state alpha disintegration energy, $Q_{\alpha,0}$, also includes the energy of any nuclear transitions that take place in the daughter produced.
10-33	maximum beta-particle energy	E_β	maximum kinetic energy (ISO 80000-4) of the emitted beta particle produced in the nuclear disintegration process	eV J kg m^2 s^{-2}	The maximum kinetic energy corresponds to the highest energy of the beta spectrum.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-34	beta disintegration energy	Q_β	sum of the maximum beta-particle kinetic energy (item 10-33) and the recoil energy (ISO 80000-5) of the atom produced in a reference frame in which the emitting nucleus is at rest before its disintegration	eV J kg m^2 s^{-2}	For positron emitters, the energy for the production of the annihilation radiation created in the combination of an electron with the positron is part of the beta disintegration energy. The ground-state beta disintegration energy, $Q_{\beta,0}$, also includes the energy of any nuclear transitions that take place in the daughter product.
10-35	internal conversion factor	α	quotient of the number of internal conversion electrons and the number of gamma quanta emitted by the radioactive atom in a given transition, where a conversion electron represents an orbital electron emitted through the radioactive decay	1	The quantity $\alpha/(\alpha+1)$ is also used and called the internal-conversion fraction. Partial conversion fractions referring to the various electron shells K, L, ... are indicated by α_K, α_L, …. α_K/α_L is called the K-to-L internal conversion ratio.
10-36	particle emission rate	$\dot{N}$	differential quotient of N with respect to time, where N is the number of particles being emitted from an infinitesimally small volume element in the time interval of duration dt (ISO 80000-3), and dt: $\dot{N}=\frac{\mathrm{d}N}{\mathrm{d}t}$	1	Usually the kind of particles is specified, e.g. neutron emission rate or alpha particle emission rate.
10-37.1	reaction energy	Q	in a nuclear reaction, sum of the kinetic energies (ISO 80000-4) and photon energies (ISO 80000-5) of the reaction products minus the sum of the kinetic and photon energies of the reactants	eV J kg m^2 s^{-2}	For exothermic nuclear reactions, $Q>0$. For endothermic nuclear reactions, $Q<0$.
10-37.2	resonance energy	E_r E_{res}	kinetic energy (ISO 80000-4) of an incident particle, in the reference frame of the target, corresponding to a resonance in a nuclear reaction	eV J kg m^2 s^{-2}	The energy of the resonance corresponds to the difference of the energy levels involved of the nucleus.
10-38.1	cross section <atomic physics>	σ	for a specified target entity and for a specified reaction or process produced by incident charged or uncharged particles of a given	m^2 b	The type of process is indicated by subscripts, e.g. absorption cross section σ_a,

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			type and energy, the quotient of the mean number of such reactions or processes and the incident-particle fluence (item 10-43)		scattering cross section σ_s, fission cross section σ_f. 1 barn (b) = 10^{-28} m^2
10-38.2	total cross section <atomic physics>	σ_{tot} σ_T	sum of all cross sections (item 10-38.1) corresponding to the various reactions or processes between an incident particle of specified type and energy (ISO 80000-5) and a target entity	m^2 b	In the case of a narrow unidirectional beam of incident particles, this is the effective cross section for the removal of an incident particle from the beam. See the Remarks for item 10-52. 1 barn (b) = 10^{-28} m^2
10-39	direction distribution of cross section <atomic physics>	σ_Ω	differential quotient of σ with respect to Ω, where σ is the cross section (item 10-38.1) for ejecting or scattering a particle into a specified direction, and Ω is the solid angle (ISO 80000-3) around that direction: $\sigma_\Omega = \mathrm{d}\sigma/\mathrm{d}\Omega$	m^2 sr^{-1} m^2	Quantities listed under items 10-39, 10-40 and 10-41 are sometimes called differential cross sections. The type of interaction needs to be specified.
10-40	energy distribution of cross section <atomic physics>	σ_E	differential quotient of σ with respect to energy, where σ is the cross section (item 10-38.1) for a process in which the energy E (ISO 80000-5) of the ejected or scattered particle is between E and E+dE: $\sigma_E = \mathrm{d}\sigma/\mathrm{d}E$	m^2/J kg^{-1} s^2	
10-41	direction and energy distribution of cross section <atomic physics>	$\sigma_{\Omega,E}$	partial differential quotient of σ with respect to solid angle and energy, where σ is the cross section (item 10-38.1) for ejecting or scattering a particle into a solid angle dΩ around a specified direction and with an energy between E and E+dE: $\sigma_{\Omega,E} = \frac{\partial^2 \sigma}{\partial \Omega \partial E}$	m^2/(J sr) kg^{-1} s^2	
10-42.1	volumic cross section, macroscopic cross section <atomic physics>	Σ	product of the number density n_a of the atoms and of the cross section (item 10-38.1) σ_a for a given type of atoms: $\Sigma = n_a \sigma_a$	m^{-1}	When the target particles of the medium are at rest, $\Sigma = 1/l$, where l is the mean free path (item 10-71).

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-42.2	volumic total cross section, macroscopic total cross section <atomic physics>	Σ_{tot} Σ_{T}	product of the number density n_a of the atoms and the cross section (item 10-38.1) σ_{tot} for a given type of atoms: $\Sigma_{\mathrm{tot}} = n_a\,\sigma_{\mathrm{tot}}$	m^{-1}	See the Remarks for item 10-49.
10-43	particle fluence	Φ	differential quotient of N with respect to a, where N is the number of particles incident on a sphere of cross-sectional area a (item 10-38.1): $\Phi = \frac{\mathrm{d}N}{\mathrm{d}a}$	m^{-2}	The word “particle” is usually replaced by the name of a specific particle, for example *proton* fluence. If a flat area of size dA is passed perpendicularly by a number of dN particles, the corresponding particle fluence is: $\Phi = \frac{\mathrm{d}N}{\mathrm{d}A}$
10-43 *(cont.)*					A plane area of size dA crossed at an angle α with respect to the surface normal by a number of dN particles results in the particle fluence: $\Phi = \frac{\mathrm{d}N}{\cos(\alpha)\mathrm{d}A}$ In report 85a of the ICRU a definition with an equivalent meaning is given as: The fluence, Φ, is the quotient of dN and da, where dN is the number of particles incident on a sphere of cross-sectional area da: $\Phi = \frac{\mathrm{d}N}{\mathrm{d}a}$. See also section 0.3.
10-44	particle fluence rate	$\dot{\Phi}$	differential quotient of fluence Φ (item 10-43) with respect to time (ISO 80000-3):	$\mathrm{m}^{-2}\ \mathrm{s}^{-1}$	The word “particle” is usually replaced by the name of a specific particle, for example proton fluence rate.

Item No.	Quantity			Unit	Remarks
	Name	**Symbol**	**Definition**		
			$\dot{\Phi}=\frac{\mathrm{d}\Phi}{\mathrm{d}t}$		The distribution function expressed in terms of speed and energy, $\dot{\Phi}_v$ and $\dot{\Phi}_E$, are related to by: $\dot{\Phi}=\int\dot{\Phi}_v\mathrm{d}v=\int\dot{\Phi}_E\mathrm{d}E$.
10-44 *(cont.)*					This quantity has also been termed particle flux density. Because the word “density” has several connotations, the term “fluence rate” is preferred. For a radiation field composed of particles of velocity v, the fluence rate is equal to $n \cdot v$ where n is the particle number density. See Remarks for item 10-43. In report 85a of the ICRU a definition with an equivalent meaning is given as: The fluence rate, $\dot{\Phi}$, is the quotient of $\mathrm{d}\Phi$ and dt, where $\mathrm{d}\Phi$ is the increment of the fluence in the time interval dt: $\dot{\Phi}=\frac{\mathrm{d}\Phi}{\mathrm{d}t}$. See also section 0.3.
10-45	radiant energy <ionizing radiation>	R	mean energy (ISO 80000-5), excluding rest energy (item 10-3), of the particles that are emitted, transferred, or received	eV J kg m^2 s^{-2}	For particles of energy E (excluding rest energy), the radiant energy, R, is equal to the product $N \cdot E$ where N is the number of the particles that are emitted, transferred, or received The distributions, N_E and R_E, of the particle number and the radiant energy with respect to energy are given by $N_E = \mathrm{d}N/\mathrm{d}E$ and $R_E = \mathrm{d}R/\mathrm{d}E$, respectively, where d$N$ is the number of particles with energy between E

Item No.	Quantity			Unit	Remarks
	Name	**Symbol**	**Definition**		
					and E+dE, and dR is their radiant energy. The two distributions are related by $R_E = E \cdot N_E$.
10-46	energy fluence	Ψ	differential quotient of radiant energy R (item 10-45) incident on a sphere of cross-sectional area (item 10-38.1) a with respect to that area: $\Psi = \frac{\mathrm{d}R}{\mathrm{d}a}$	eV/m^2 J/m^2 kg s^{-2}	In report 85a of the ICRU a definition with an equivalent meaning is given as: The energy fluence, Ψ, is the quotient of dR and da, where dR is the radiant energy incident on a sphere of cross-sectional area da: $\Psi = \frac{\mathrm{d}R}{\mathrm{d}a}$. See also section 0.3.
10-47	energy fluence rate	$\dot{\Psi}$	differential quotient of the energy fluence Ψ (item 10-46) with respect to time (ISO 80000-3): $\dot{\Psi} = \frac{\mathrm{d}\Psi}{\mathrm{d}t}$	W/m^2 kg s^{-3}	In report 85a of the ICRU a definition with an equivalent meaning is given as: The energy-fluence rate, $\dot{\Psi}$, is the quotient of $\mathrm{d}\Psi$ by dt, where $\mathrm{d}\Psi$ is the increment of the energy fluence in the time interval dt: $\dot{\Psi} = \frac{\mathrm{d}\Psi}{\mathrm{d}t}$. See also section 0.3.
10-48	particle current density	$\boldsymbol{J}$ $\boldsymbol{S}$	vector whose component in direction of an area normal is given by: $J_n = \int \Phi_\Omega(\theta,\alpha)\cos(\theta)\,\mathrm{d}\Omega$ where $\Phi_\Omega(\theta,\alpha)$ is the directional distribution of the particle fluence rate (item 10-44), and θ and α are polar and azimuthal angles, respectively	m^{-2} s^{-1}	Usually the word “particle” is replaced by the name of a specific particle, for example proton current. Symbol $\boldsymbol{S}$ is recommended when there is a possibility of confusion with the symbol $\boldsymbol{J}$ for electric current density. For neutron current, the symbol $\boldsymbol{J}$ is generally used. The distribution functions expressed in terms of speed and energy, $\boldsymbol{J}_v$ and $\boldsymbol{J}_E$, are related to $\boldsymbol{J}$ by:

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					$\boldsymbol{J}=\int \boldsymbol{J}_\nu \mathrm{d}\nu=\int \boldsymbol{J}_E \mathrm{d}E$. The directional distribution of the particle fluence rate is also denoted as particle radiance.
10-49	linear attenuation coefficient <ionizing radiation>	μ μ_l	for uncharged particles of a given type and energy the differential quotient *n* with respect to *l,* where *n* is the fraction of *N* incoming particles that experience interactions in traversing a distance (ISO 80000-3) *l* in a given material: $\mu=\frac{\mathrm{d}n}{\mathrm{d}l}=\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}l}$ where d*N* is the number of particles that experience interactions in traversing d*l*	m^{-1}	μ is equal to the macroscopic total cross section Σ_{tot} for the removal of particles from the beam. Using the relation $\mu_m = \mu/\rho$ between the linear attenuation coefficient μ, the mass attenuation coefficient μ_m (item 10-50) and the density ρ, the definition given for the mass attenuation coefficient in report 85a of the ICRU can be applied to the linear attenuation coefficient resulting in:
10-49 *(cont.)*					The linear attenuation coefficient, μ, of a material, for uncharged particles of a given type and energy, is the quotient of d*N*/*N* by d*l*, where d*N*/*N* is the mean fraction of the particles that experience interactions in traversing a distance d*l* in the material: $\mu=\frac{1}{\mathrm{d}l}\frac{\mathrm{d}N}{N}$. This definition has an equivalent meaning as the one given in column 4 of this item. See also section 0.3.
10-50	mass attenuation coefficient <ionizing radiation>	μ_m	quotient of the linear attenuation coefficient μ (item 10-49) and the mass density ρ (ISO 80000-4) of the medium: $\mu_m = \mu/\rho$	$\mathrm{kg}^{-1}\ \mathrm{m}^2$	
10-51	molar attenuation coefficient	μ_c	quotient of linear attenuation coefficient μ (item 10-49) and the amount c (ISO 80000-9) of the medium:	$\mathrm{m}^2\ \mathrm{mol}^{-1}$	

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			$\mu_c = \mu / c$		
10-52	atomic attenuation coefficient	μ_a	quotient of the linear attenuation coefficient μ (item 10-49) and the number density (item 10-62.1), n, of atoms in the substance: $\mu_a = \mu / n$	m^2	μ is equal to the total cross section σ_{tot} for the removal of particles from the beam. See also item 10-38.2.
10-53	half-value thickness	$d_{1/2}$	thickness (ISO 80000-3) of the attenuating layer that reduces the quantity of interest of a unidirectional beam of infinitesimal width to half of its initial value	m	For exponential attenuation, $d_{1/2} = \ln(2)/\mu$. The quantity of interest is often the air kerma or exposure.
10-54	total linear stopping power linear stopping power	S S_l	for charged particles of a given type and energy E_0 the differential quotient of E with respect to x, where E is the mean energy (ISO 80000-4) lost by the charged particles in traversing a distance (ISO 80000-3) x in the given material: $S = -\frac{dE}{dx}$	eV/m J/m kg m s^{-2}	The total linear stopping power is sometimes also called stopping power. Both electronic losses and radiative losses are included. The quotient of the total linear stopping power of a substance and that of a reference substance is called the relative linear stopping power. See also item 10-85. Using the relation $S_m = S/\rho$ between the total mass stopping power S_m (item 10-55), the total linear stopping power S, and the density ρ, the definition given for the mass stopping in report 85a of the ICRU can be applied to that of the total linear stopping power resulting in: The linear stopping power, S, of a material, for charged particles of a given type and energy, is the quotient of dE by dl, where dE is the mean energy lost by the charged particles in traversing a distance dl in the material: $S = -\frac{dE}{dx}$.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					This definition has an equivalent meaning as the one given in column 4 of this item. See also section 0.3.
10-55	total mass stopping power mass stopping power	S_m	quotient of the total linear stopping power S (item 10-54) and the mass density ρ (ISO 80000-4) of the material: $S_m = S/\rho$	eV $\mathrm{m^{-2}/kg}$ $\mathrm{J\ m^2/kg}$ $\mathrm{m^4\ s^{-2}}$	The quotient of total mass stopping power of a material and that of a reference material is called relative mass stopping power.
10-56	mean linear range	R R_l	mean total rectified path length (ISO 80000-3) travelled by a particle in the course of slowing down to rest in a given material averaged over a group of particles having the same initial energy (ISO 80000-5)	m	
10-57	mean mass range	R_ρ R_m	product of the mean linear range (item 10-56) R and the mass density ρ (ISO 80000-4) of the material: $R_\rho = R\rho$	$\mathrm{kg\ m^{-2}}$	
10-58	linear ionization	N_{il}	differential quotient of q with respect to l, where q is the average total charge (IEC 80000-6) of all positive ions produced by an ionizing charged particle over a path l (ISO 80000-3), divided by the elementary charge, e (ISO 80000-1): $N_{il} = \frac{1}{e}\frac{\mathrm{d}q}{\mathrm{d}l}$	$\mathrm{m^{-1}}$	Ionization due to secondary ionizing particles is included.
10-59	total ionization	N_i	quotient of the total mean charge of all positive ions produced by an ionizing charged particle along its entire path and along the paths of any secondary charged particles, and the elementary charge, e (ISO 80000-1)	1	$N_\mathrm{i} = \int N_{il}\ \mathrm{d}l$ See item 10-58.
10-60	average energy loss per elementary charge produced	W_i	quotient of the initial kinetic energy E_k (ISO 80000-4) of an ionizing charged particle and the total ionization N_i (item 10-59) produced by that particle: $W_\mathrm{i} = E_\mathrm{k}/N_\mathrm{i}$	eV J $\mathrm{kg\ m^2\ s^{-2}}$	The name “average energy loss per ion pair formed” is usually used, although it is ambiguous. In the practical dosimetry of ionizing radiation the term W/e, the quotient of W, the average energy deposited in dry air per ion pair formed, and e, the elementary

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					charge, is used as the factor which, when multiplied with the electric charge of one sign carried by all ion pairs formed in dry air of given mass, gives the energy deposited in this amount of dry air in the form of excitations and ionizations.
10-60 *(cont.)*					In ICRU Report 85a, the mean energy expended in a gas per ion pair formed, W, is the quotient of E by N, where N is the mean total liberated charge of either sign, divided by the elementary charge when the initial kinetic energy E of a charged particle introduced into the gas is completely dissipated in the gas. Thus, $W = E/N$. It follows from the definition of W that the ions produced by bremsstrahlung or other secondary radiation emitted by the initial and secondary charged particles are included in N.
10-61	mobility	μ μ_m	quotient of average drift speed (ISO 80000-3) imparted to a charged particle in a medium by an electric field, and the electric field strength (IEC 80000-6)	$\mathrm{m}^2/(\mathrm{V\ s})$ $\mathrm{kg}^{-1}\ \mathrm{s}^2\ \mathrm{A}$	
10-62.1	particle number density	n	quotient of the mean number N of particles in the volume (ISO 80000-3) V and volume: $n = N/V$	m^{-3}	n is the general symbol for the number density of particles. The distribution functions expressed in terms of speed and energy, n_v and n_E, are related to n by: $n = \int n_v \ \mathrm{d}v = \int n_E \ \mathrm{d}E$. The word “particle” is usually replaced by the name of a specific particle, for example *neutron* number density.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-62.2	ion number density, ion density	n^+ n^-	quotient of the number of positive and negative ions, N^+ and N^-, respectively, in the volume V (ISO 80000-3), and that volume: $n^+ = N^+/V$, $n^- = N^-/V$	m^{-3}	
10-63	Recombination coefficient	α	coefficient in the law of recombination: $-\frac{\mathrm{d}n^+}{\mathrm{d}t}=-\frac{\mathrm{d}n^-}{\mathrm{d}t}=\alpha\cdot n^+ n^-$ where n^+ and n^- are the ion number densities (item 10-62.2) of positive and negative ions, respectively, recombined during a time interval of duration dt (ISO 80000-3)	$\text{m}^3\ \text{s}^{-1}$	The widely used term “recombination factor” is not correct because “factor” should only be used for quantities with dimension 1. The terms $\frac{\mathrm{d}n^+}{\mathrm{d}t}$, $\frac{\mathrm{d}n^-}{\mathrm{d}t}$ are differential quotients.
10-64	diffusion coefficient, diffusion coefficient for particle number density	D D_n	proportionality constant between the particle current density $\boldsymbol{J}$ (item 10-48) and the gradient of the particle number density n (item 10-62.1): $\boldsymbol{J}=-D\cdot\nabla n$	$\text{m}^2\ \text{s}^{-1}$	The word “particle” is usually replaced by the name of a specific particle, for example *neutron* number density. For a particle of a given speed v: $D_n(v)=-\frac{J_{v,x}}{\partial n_v/\partial x}$
10-65	diffusion coefficient for fluence rate	D_ϕ D	proportionality constant between the particle current density $\boldsymbol{J}$ (item 10-48) and the gradient of the particle fluence rate $\dot{\Phi}$ (item 10-44): $\boldsymbol{J}=-D\cdot\nabla\dot{\Phi}$	m	For a particle of a given speed v: $D_{\dot{\Psi}}(v)=-\frac{J_{v,x}}{\partial\dot{\Psi}_v/\partial x}$ and $v\cdot D_{\dot{\Psi}}(v)=-D_n(v)$
10-66	particle source density	S	quotient of the mean rate of production of particles in a volume, and that volume (ISO 80000-3)	$\text{m}^{-3}\ \text{s}^{-1}$	The word “particle” is usually replaced by the name of a specific particle, for example *proton* source density. The distribution functions expressed in terms of speed and energy, S_v and S_E, are related to S by:

Item No.	Quantity			Unit	Remarks
	Name	**Symbol**	**Definition**		
					$S=\int S_v \, \mathrm{d}v=\int S_E \, \mathrm{d}E$.
10-67	slowing-down density	q	differential quotient of n with respect to time, where n is the number density of particles that are slowed down in a time interval of duration (ISO 80000-3) t: $q=-\frac{\mathrm{d}n}{\mathrm{d}t}$	$\mathrm{m}^{-3}\ \mathrm{s}^{-1}$	
10-68	resonance escape probability	p	in an infinite medium, the probability that a neutron slowing down will traverse all or some specified portion of the range of resonance energies (item 10-37.2) without being absorbed	1	
10-69	lethargy	u	for a neutron of kinetic energy E (ISO 80000-4) : $u = \ln(E_0/E)$, where E_0 is a reference energy	1	Lethargy is also referred to as logarithmic energy decrement.
10-70	average logarithmic energy decrement	ζ	average value of the increase in lethargy (item 10-69) in elastic collisions between neutrons and nuclei whose kinetic energy (ISO 80000-4) is negligible compared with that of the neutrons	1	
10-71	mean free path <atomic physics>	l λ	average distance (ISO 80000-3) that particles travel between two successive specified reactions or processes	m	See the Remarks for item 10-42.1.
10-72.1	slowing-down area	L_s^2 L_sl^2	in an infinite homogenous medium, one-sixth of the mean square of the distance (ISO 80000-3) between the neutron source and the point where a neutron reaches a given energy (ISO 80000-5)	m^2	
10-72.2	diffusion area	L^2	in an infinite homogenous medium, one-sixth of the mean square distance (ISO 80000-3) between the point where a neutron enters a specified class and the point where it leaves this class	m^2	The class of neutrons must be specified, e.g. thermal.
10-72.3	migration area	M^2	sum of the slowing-down area (item 10-72.1) from fission energy to thermal energy (ISO 80000-5) and the diffusion area (item 10-72.2) for thermal neutrons	m^2	
10-73.1	slowing-down length	L_s L_sl	square root of the slowing down area L_s^2 (item 10-72.1):	m	

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			$L_s = \sqrt{L_s^2}$		
10-73.2	diffusion length <atomic physics>	L	square root of the diffusion area L^2 (item 10-72.2): $L = \sqrt{L^2}$	m	
10-73.3	migration length	M	square root of the migration area M^2 (item 10-72.3): $M = \sqrt{M^2}$	m	
10-74.1	neutron yield per fission	ν	average number of fission neutrons, both prompt and delayed, emitted per fission event	1	
10-74.2	neutron yield per absorption	η	average number of fission neutrons, both prompt and delayed, emitted per neutron absorbed in a fissionable nuclide or in a nuclear fuel, as specified	1	ν/η is equal to the quotient of the macroscopic cross section for fission and that for absorption, both for neutrons in the fuel material.
10-75	fast fission factor	φ	in an infinite medium, the quotient of the mean number of neutrons produced by fission due to neutrons of all energies (ISO 80000-5) and the mean number of neutrons produced by fissions due to thermal neutrons only	1	The class of neutrons must be specified, e.g. thermal.
10-76	thermal utilization factor	f	in an infinite medium, the quotient of the number of thermal neutrons absorbed in a fissionable nuclide or in a nuclear fuel, as specified, and the total number of thermal neutrons absorbed	1	
10-77	non-leakage probability	Λ	probability that a neutron will not escape from the reactor during the slowing-down process or while it diffuses as a thermal neutron	1	
10-78.1	multiplication factor	k	quotient of the total number of fission or fission-dependent neutrons produced in the duration of a time interval and the total number of neutrons lost by absorption and leakage in that duration	1	
10-78.2	infinite multiplication factor	k_∞	multiplication factor (item 10-78.1) for an infinite medium or for an infinite repeating lattice	1	For a thermal reactor, $k_\infty = \eta \cdot \varepsilon \cdot p \cdot f$

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
10-79	reactor time constant	T	duration (ISO 80000-3) required for the neutron fluence rate (item 10-44) in a reactor to change by the factor e when the fluence rate is rising or falling exponentially	s	Also called reactor period.
10-80.1	energy imparted	ε	sum of all energy deposits in a given volume: $\varepsilon = \sum_i \varepsilon_i$ where the summation is performed over all energy (ISO 80000-5) deposits ε_i of interaction i in that volume	eV J kg m^2 s^{-2}	Energy imparted is a stochastic quantity. ε_i is given by: $\varepsilon_i = \varepsilon_{\text{in}} - \varepsilon_{\text{out}} + Q$ where ε_{in} is the energy (ISO 80000-5) of the incident ionizing particle, excluding rest energy (item 10-3), ε_{out} is the sum of the energies (ISO 80000-5) of all ionizing particles leaving the interaction, excluding rest energy (item 10-3), and Q is the change in the rest energies (item 10-3) of the nucleus and of all particles involved in the interaction. $Q > 0$ means decrease of rest energy; $Q < 0$ means increase of rest energy. Stochastic quantities such as the energy imparted and the specific energy imparted (item 10-81.2) 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 expectation values of the probability distributions. Non-stochastic quantities such as particle fluence (item 10-43), absorbed

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					dose (item 10-81.1) and kerma (item 10-86.1) are based on these expectation values.
10-80.2	mean energy imparted	$\bar{\varepsilon}$	expectation value of the energy imparted (item 10-80.1): $\bar{\varepsilon} = R_{\text{in}} - R_{\text{out}} + \sum Q$ where R_{in} is the radiant energy (item 10-45) of all those charged and uncharged ionizing particles that enter the volume, R_{out} is the radiant energy of all those charged and uncharged ionizing particles that leave the volume, and $\sum Q$ is the sum of all changes of the rest energy (item 10-3) of nuclei and elementary particles that occur in that volume	eV J kg m^2 s^{-2}	Sometimes, it has been called the integral absorbed dose. $Q > 0$ means decrease of rest energy; $Q < 0$ means increase of rest energy.
10-81.1	absorbed dose	D	differential quotient of $\bar{\varepsilon}$ with respect to m, where $\bar{\varepsilon}$ is the mean energy (ISO 80000-5) imparted by ionizing radiation to matter of mass (ISO 80000-4) m: $D = \frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$	Gy J/kg m^2 s^{-2}	The gray is a special name for joule per kilogram, to be used as the coherent SI unit for absorbed dose. 1 Gy = 1 J/kg $\bar{\varepsilon} = \int D \, \mathrm{d}m$ where dm is the element of mass of the irradiated matter. In the limit of a small domain, the mean specific energy $\bar{z} = \frac{\Delta\bar{\varepsilon}}{\Delta m}$ is equal to the absorbed dose D. The absorbed dose can also be expressed in terms of the volume of the mass element by:

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					$D=\frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}=\frac{\mathrm{d}\bar{\varepsilon}}{\rho\ \mathrm{d}V}$
10-81.1 *(cont.)*					where ρ is the mass density of the mass element. In report 85a of the ICRU a definition with an equivalent meaning is given as: The absorbed dose, D, is the quotient of $\mathrm{d}\bar{\varepsilon}$ by dm, where $\mathrm{d}\bar{\varepsilon}$ is the mean energy imparted by ionizing radiation to matter of mass dm: $D=\frac{\mathrm{d}\bar{\varepsilon}}{\mathrm{d}m}$.
10-81.2	specific energy imparted	z	quotient of the energy imparted ε (item 10-80.1) and the mass m (ISO 80000-4) of the matter in a given volume element: $z=\frac{\varepsilon}{m}$	Gy J/kg $\mathrm{m}^2\ \mathrm{s}^{-2}$	z is a stochastic quantity. In the limit of a small domain, the mean specific energy $\bar{z}$ is equal to the absorbed dose D. The specific energy imparted can be due to one or more (energy-deposition) events.
10-82	quality factor <ionizing radiation>	Q	factor in the calculation and measurement of dose equivalent (item 10-83.1), by which the absorbed dose (item 10-81.1) is to be weighted in order to account for different biological effectiveness of radiations, for radiation protection purposes	1	Q is determined by the linear energy transfer (item 10-85) for $\Delta\to\infty$, L_∞ (often denoted as L or LET), of charged particles passing through a small volume element at this point (the value of L_∞ refers to water, not to tissue; the difference, however, is small). The relationship between L and Q is given in ICRP Publication 103 (ICRP, 2007).
10-83.1	dose equivalent	H	product of the absorbed dose D (item 10-81.1) to tissue at the point of interest and the quality factor Q (item 10-82) at that point: $H = DQ$	Sv J/kg $\mathrm{m}^2\ \mathrm{s}^{-2}$	The sievert (Sv) is a special name for joule per kilogram, and is the coherent SI unit for dose equivalent. 1 Sv = 1 J/kg

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					The dose equivalent at a point in tissue is given by: $H = \int_0^\infty Q(L) D_L \,\mathrm{d}L$ where $D_L = \mathrm{d}D/\mathrm{d}L$ is the distribution of D in L at the point of interest. See ICRP Publication 103 (ICRP, 2007). The quantities measured with radiation protection dosimeters are based on the definition $H = Q\,D$. If various radiation qualities i have to be simultaneously accounted for, the definition is: $H = \sum_i Q_i D_i$.
10-83.1 *(cont.)*					In ICRU 51 this quantity is denoted as “dose equivalent”. In order to quantify the radiation exposition of the human body and to specify dose limits, use is made of a quantity defined in ICRP 103, the “equivalent dose to a tissue or organ”: $H_\mathrm{T} = w_\mathrm{T} \sum_\mathrm{R} w_\mathrm{R} D_\mathrm{T,R}$. The weighting factors w_T for various tissues and organs T and w_R for various radiation qualities R have been numerically laid down in ICRP 103. $D_\mathrm{T,R}$ is the mean absorbed dose to tissue within a tissue or organ T, imparted by radiation with radiation quality R.
10-83.2	dose equivalent rate	$\dot{H}$	differential quotient of dose equivalent H (item 10-83.1) with respect to time (ISO 80000-3):	Sv/s W/kg	1 Sv/s = 1 W/kg See the remarks for item 10-83.1.

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			$\dot{H}=\frac{\mathrm{d}H}{\mathrm{d}t}$	$\mathrm{m}^2\ \mathrm{s}^{-3}$	
10-84	absorbed-dose rate	$\dot{D}$	differential quotient of the absorbed dose D (item 10-81.1) with respect to time (ISO 80000-3): $\dot{D}=\frac{\mathrm{d}D}{\mathrm{d}t}$	Gy/s W/kg $\mathrm{m}^2\ \mathrm{s}^{-3}$	1 Gy/s = 1 W/kg See the remarks for item 10-81.1. In report 85a of the ICRU a definition with an equivalent meaning is given as: The absorbed-does rate, $\dot{D}$, is the quotient of dD by dt, where dD is the increment of absorbed does in the time interval dt: $\dot{D}=\frac{\mathrm{d}D}{\mathrm{d}t}$.
10-85	linear energy transfer	L_Δ	quotient of the mean energy (ISO 80000-4) dE_Δ lost by the charged particles due to electronic interactions in traversing a distance (ISO 80000-3) dl, minus the mean sum of the kinetic energies in excess of Δ of all the electrons released by the charged particles and dl: $L_\Delta=\frac{\mathrm{d}E_\Delta}{\mathrm{d}l}$	eV/m J/m $\mathrm{kg\ m\ s}^{-2}$	This quantity is not completely defined unless Δ is specified, i.e. the maximum kinetic energy of secondary electrons whose energy is considered to be “locally deposited.” Δ may be expressed in eV. Note that the abbreviation LET specifically refers to the quantity L_∞ mentioned in the remark to 10-82.
10-86.1	kerma	K	for uncharged ionizing radiation, differential quotient of E_{tr} with respect to m, where E_{tr} is the mean sum of the initial kinetic energies (ISO 80000-4) of all the charged ionizing particles liberated in a mass (ISO 80000-4) m of a material: $K=\frac{\mathrm{d}E_{\mathrm{tr}}}{\mathrm{d}m}$	Gy J/kg $\mathrm{m}^2\ \mathrm{s}^{-2}$	1 Gy = 1 J/kg See the remarks for item 10-81.1. The name “kerma” is derived from Kinetic Energy Released in MAtter (or MAss or MAterial). The quantity dE_{tr} includes also the kinetic energy of the charged particles emitted in the decay of excited atoms, molecules, or nuclei. When the mass element dm consists of air the term air kerma is used. It can be convenient to refer to a value of air kerma in

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					free space or at a point inside a material different from air, e.g. to the air kerma at a point inside a water phantom. In report 85a of the ICRU a definition with an equivalent meaning is given as: The kerma, K, for ionizing uncharged particles, is the quotient of dE_{tr} by dm, where dE_{tr} is the mean sum of the initial kinetic energies of all the charged particles liberated in a mass dm of a material by the uncharged particles incident on dm: $K = \frac{\mathrm{d}E_{tr}}{\mathrm{d}m}$.
10-86.2	kerma rate	$\dot{K}$	differential quotient of kerma (item 10-86.1) with respect to time (ISO 80000-3): $\dot{K} = \frac{\mathrm{d}K}{\mathrm{d}t}$	Gy/s W/kg $m^2\ s^{-3}$	1 Gy/s = 1 W/kg See the Remarks for item 10-81.1. In report 85a of the ICRU a definition with an equivalent meaning is given as: The kerma rate, $\dot{K}$, is the quotient of dK by dt, where dK is the increment of kerma in the time interval dt: $\dot{K} = \frac{\mathrm{d}K}{\mathrm{d}t}$.
10-87	mass energy-transfer coefficient	μ_{tr}/ρ	for ionizing uncharged particles of a given type and energy, the differential quotient of R_{tr} with respect to l: $\frac{\mu_{tr}}{\rho} = \frac{1}{\rho}\frac{1}{R}\frac{\mathrm{d}R_{tr}}{\mathrm{d}l}$ where R_{tr} is the mean energy (ISO 80000-5) that is transferred to kinetic energy (ISO 80000-4) of charged particles by interactions of the uncharged particles of incident radiant energy R (item 10-	$kg^{-1}\ m^2$	$\mu_{tr}/\rho = \dot{K}/\psi$, where $\dot{K}$ is kerma rate (item 10-86.2) and Ψ is energy fluence rate (item 10-47). The quantity: $\mu_{en}/\rho = (\mu_{tr}/\rho)(1-g)$ where g is mean fraction of the kinetic energy of the liberated charged particles that is lost in radiative processes in the

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			45) in traversing a distance (ISO 80000-3) l in the material of density (ISO 80000-4) ρ, divided by ρ and R		material, is called mass energy-absorption coefficient. The mass energy-absorption coefficient of a compound material depends on the stopping power of the material. Thus, its evaluation cannot, in principle, be reduced to a simple summation of the mass energy-absorption coefficient of the atomic constituents. Such a summation can provide an adequate approximation when the value of g is sufficiently small.
10-87 *(cont.)*					In report 85a of the ICRU a definition with an equivalent meaning is given as: The mass energy-transfer coefficient, μ_{tr}/ρ, of a material, for uncharged particles of a given type and energy, is the quotient of $\text{d}R_{\text{tr}}/R$ by $\rho\,\text{d}l$, where $\text{d}R_{\text{tr}}$ is the mean energy that is transferred to kinetic energy of charged particles by interactions of the uncharged particles of incident radiant energy R in traversing a distance $\text{d}l$ in the material of density ρ: $\frac{\mu_{\text{tr}}}{\rho}=\frac{1}{\rho\,\text{d}l}\frac{\text{d}R_{\text{tr}}}{R}$.
10-88	exposure <ionizing radiation>	X	for X- or gamma radiation the differential quotient of q with respect to m, where q is the absolute value of the mean total electric charge of the ions of one sign produced when all the electrons and positrons liberated or created by photons incident on an element of dry air with mass m (ISO 80000-4) are completely stopped in dry air:	C/kg kg^{-1} s A	The ionization produced by electrons emitted in atomic or molecular relaxation is included in dq. The ionization due to photons emitted by radiative processes (i.e. bremsstrahlung and fluorescence photons) is not included in dq. This quantity should not be confused with the quantity photon exposure (ISO 80000-7),

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
			$X = \frac{\mathrm{d}q}{\mathrm{d}m}$		radiation exposure (ISO 80000-7), or the quantity luminous exposure (ISO 80000-7). It can be convenient to refer to a value of exposure in free space or at a point inside a material different from air, e.g. to the exposure at a point inside a water phantom. The exposure is related to the air kerma, K_a, (see item 10-86.1) by: $X = \frac{e\ (\ 1-g)}{W} K_a$,
10-88 *(cont.)*					where e is the elementary charge (ISO 80000-1), W the average energy loss per elementary charge produced (item 10-60), and g is the fraction of the kinetic energy of liberated charged particles that is lost in radiative processes. In report 85a of the ICRU a definition with an equivalent meaning is given as: The exposure, X, is the quotient of dq by dm, where dq is the absolute value of the mean total charge of the ions of one sign produced when all the electrons and positrons liberated or created by photons incident on a mass dm of dry air are completely stopped in dry air: $X = \frac{\mathrm{d}q}{\mathrm{d}m}$.
10-89	exposure rate	$\dot{X}$	differential quotient of the exposure X (item 10-88) with respect to time (ISO 80000-3): $\dot{X} = \frac{\mathrm{d}X}{\mathrm{d}t}$	C/(kg s) kg^{-1} A	1 C/(kg s) = 1 A/kg In report 85a of the ICRU a definition with an equivalent meaning is given as:

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
					The exposure rate, $\dot{X}$, is the quotient of dX by dt, where dX is the increment of exposure in the time interval dt: $\dot{X}=\frac{\mathrm{d}X}{\mathrm{d}t}$.

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