International Standard ISO 31/10

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Quantities and units of nuclear reactions and ionizing radiations

Grandeurs et unités de réactions nucléaires et rayonnements ionisants

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ISO 31/10-1980 (E)

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 31/10 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.

The second edition cancels and replaces the first edition (i.e. ISO 31/10-1973).

This reprint of the second edition 1980 incorporates the erratum of 1981-12-01 (see 10-19.1 and 10-20.1 in the annex).

Printed in Switzerland

Quantities and units of nuclear reactions and ionizing radiations

Introduction

This document, containing a table of *quantities and units of nuclear reactions and ionizing radiations*, is part 10 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 :

a) *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.

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

c) *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

In this document the term "particle" includes particles without a rest mass as well as particles having a rest mass.

Distribution functions in terms of energy, velocity, solid angle etc. correspond to several quantities listed in this document. The subscripts E, v and Ω are used as part of the symbol to indicate that the quantity has the dimension of a derivative with respect to E, v and Ω respectively. In general these distribution functions are only mentioned in the remarks column; see for example 10-12.1, 10-29.1, 10-31.1 and 10-32.1.

In the case of cross sections, some of these distribution functions are given special names and are listed as separate items.

(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
10-1.1 . . . 10-6.1

10. Nuclear reactions and ionizing radiations

Item No.	Quantity	Symbol	Definition	Remarks
10-1.1	reaction energy	Q	In the nuclear reaction, the sum of the kinetic and photon energies of the reaction products minus the sum of the kinetic and photon energies of the reactant.	For exothermic nuclear reactions $Q > 0$. For endothermic nuclear reactions $Q < 0$. For beta disintegration, see ISO 31/9.
10-2.1	resonance energy	E_r, E_{res}	The kinetic energy of an incident particle, in the reference frame of the target, corresponding to a resonance in a nuclear reaction.	
10-3.1	cross section	σ	For a specified target entity and for a specified reaction or process produced by incident charged or uncharged particles of specified type and energy, the cross section is the quotient of the probability of this reaction or process for this target entity and the particle fluence of the incident particles.	The type of process is indicated with subscripts, e.g. absorption cross section σ_a, σ_A scattering cross section σ_s, σ_S fission cross section σ_f.
10-3.2	total cross section	σ_{tot}, σ_T	The sum of all cross sections corresponding to the various reactions or processes between incident particle and target particle.	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 remark to 10-16.1.
10-4.1	angular cross section	σ_Ω	Cross section for ejecting or scattering a particle into an element of solid angle, divided by this element. $\sigma = \int \sigma_\Omega \, d\Omega$	The quantities 10-4.1, 10-5.1 and 10-6.1 are sometimes called differential cross sections. In accordance with conventions used in other parts of ISO 31 angular and spectral cross sections are indicated by the use of subscripts. The information about incoming and outgoing particles may be added between parentheses, e.g. $\sigma_{\Omega,E}$ $(nE_0, pE\theta)$ or $\sigma_{\Omega,E}$ $(nE_o; p)$ or $\sigma_{\Omega,E}$ $(n;p)$. The cross section for a process in which an incoming neutron of energy E_o causes the ejection of a proton within the energy interval $(E, E + dE)$ and in the element of solid angle $d\Omega$, about the scattering angle θ is $\sigma_{\Omega,E}(nE_o, pE\theta)\, d\Omega\, dE$. Sometimes the incoming and outgoing particles are indicated by subscripts, in which case the subscripts Ω and/or E indicating the angular and/or spectral character could be placed in superscript position, e.g. $\sigma_{n,p}^{E,\theta}(E_o)$ or $\sigma_{n,p}^{E,\theta}$. If, however, the subscripts Ω and/or E are omitted completely from the cross section symbol, the angular and/or spectral character of the cross section then follows only from the occurrence of the variables θ and/or E for the outgoing particles between the parentheses, e.g. $\sigma_{n,p}$ $(E_o, E\ \theta)$ or $\sigma_{n,p}$ $(E\ \theta)$. These variables should then never be omitted.
10-5.1	spectral cross section	σ_E	Cross section for a process in which the energy of the ejected or scattered particle is in an element of energy, divided by this element. $\sigma = \int \sigma_E \, dE$	
10-6.1	spectral angular cross section	$\sigma_{\Omega,E}$	Cross section for ejecting or scattering a particle into an element of solid angle with energy in an element of energy, divided by the product of these two elements. $\sigma = \iint \sigma_{\Omega,E} \, d\Omega \, dE$	

10. Nuclear reactions and ionizing radiations

Units
10-1.a . . . 10-6.b

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
10-1.a	joule	J			
10-1.b	electronvolt	eV		1 eV = 1,602 189 2 × 10^{-19} J	See also ISO 31/3. The quantity 10-1.1 is usually expressed in electronvolts.
10-2.a	joule	J			
10-2.b	electronvolt	eV		1 eV = 1,602 189 2 × 10^{-19} J	The quantity 10-2.1 is usually expressed in electronvolts.
10-3.a	square metre	m^2			
10-3.b	barn	b	1 b = 10^{-28} m^2	1 b = 10^{-28} m^2 (exactly)	
10-4.a	square metre per steradian	m^2/sr			
10-4.b	barn per steradian	b/sr		1 b/sr = 10^{-28} m^2/sr (exactly)	
10-5.a	square metre per joule	m^2/J			
10-5.b	barn per electronvolt	b/eV		1 b/eV = 6,241 46 × 10^{-10} m^2/J	
10-6.a	square metre per steradian joule	m^2/(sr·J)			
10-6.b	barn per steradian electronvolt	b/(sr·eV)		1 b/(sr·eV) = 6,241 46 × 10^{-10} m^2/(sr·J)	

Quantities
10-7.1 . . . 10-17.1

10. Nuclear reactions and ionizing radiations (continued)

Item No.	Quantity	Symbol	Definition	Remarks
10-7.1	macroscopic cross section, cross section density	Σ	The sum of the cross sections for a reaction or process of a specified type over all atoms in a given volume, divided by that volume.	$\Sigma = n_1\sigma_1 + \ldots + n_i\sigma_i + \ldots$ (n_i is the number density and σ_i is the cross section for atoms of type i). When the target particles of the medium are at rest $\Sigma = 1/l$, where l is the mean free path, see 10-39.1. See remark to 10-13.1.
10-7.2	total macroscopic cross section, total cross section density	Σ_{tot}, Σ_T	The sum of total cross sections for all atoms in a given volume, divided by that volume.	
10-8.1 (—)	particle fluence	Φ	At a given point in space, the number of particles incident on a small sphere in a time interval, divided by the cross-sectional area of that sphere.	Usually the word particle is replaced by the name of a specific particle, for example proton fluence.
10-9.1 (—)	particle fluence rate, particle flux density	φ	$\varphi = \dfrac{d\Phi}{dt}$	See also 10-31.1, where distribution functions are also included in the "Remarks" column.
10-10.1 (—)	energy fluence	Ψ	At a given point in space, the sum of the energies, exclusive of rest energy, of all the particles incident on a small sphere in a time interval, divided by the cross sectional area of that sphere.	
10-11.1 (—)	energy fluence rate, energy flux density	ψ	$\psi = \dfrac{d\Psi}{dt}$	
10-12.1 (10-10.1)	current density of particles	J, (S)	A vector quantity the integral of whose normal component over any surface is equal to the net number of particles passing through that surface in a small time interval divided by that interval.	S is recommended when there is a possibility of confusion with the symbol J for electric current density. For neutron current density the symbol J is generally used. The distribution functions in terms of speed and energy, J_v and J_E, are related to J by $J = \int J_v \, dv = \int J_E \, dE$
10-13.1 (10-11.1)	linear attenuation coefficient	μ, μ_l	$dJ/dx = -\mu J$ where J is the current density of a beam of particles parallel to the x-direction.	μ is equal to the total macroscopic cross section Σ_{tot} for removal of particles from the beam.
10-14.1 (10-13.1)	mass attenuation coefficient	μ/ϱ, μ_m	The linear attenuation coefficient divided by the mass density of the substance.	
10-15.1 (—)	molar attenuation coefficient	μ_c	$\mu_c = \mu/c$ where c is the amount-of-substance concentration.	
10-16.1 (10-12.1)	atomic attenuation coefficient	μ_a, μ_{at}	$\mu_a = \mu/n$ where n is the number density of atoms in the substance (see also 10-27.1).	μ_a is equal to the total cross section σ_{tot} for removal of particles from the beam.
10-17.1 (10-14.1)	half-thickness, half value thickness	$d_{1/2}$	The thickness of the attenuating layer that reduces the current density of a unidirectional beam to one-half of its initial value.	For exponential attenuation $d_{1/2} = (\ln 2)/\mu$. Other half value thicknesses, such as that for attenuation of absorbed dose rate, are also used.

10. Nuclear reactions and ionizing radiations (continued)

Units
10-7.a . . . 10-17.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
10-7.a	reciprocal metre, metre to the power minus one	m^{-1}			
10-8.a	reciprocal square metre, metre to the power minus two	m^{-2}			
10-9.a	reciprocal square metre reciprocal second, metre to the power minus two second to the power minus one	$m^{-2} \cdot s^{-1}$			
10-10.a	joule per square metre	J/m^2			
10-11.a	watt per square metre	W/m^2			
10-12.a	reciprocal square metre reciprocal second, metre to the power minus two second to the power minus one	$m^{-2} \cdot s^{-1}$			
10-13.a	reciprocal metre, metre to the power minus one	m^{-1}			
10-14.a	square metre per kilogram	m^2/kg			
10-15.a	square metre per mole	m^2/mol			
10-16.a	square metre	m^2			
10-17.a	metre	m			

Quantities
10-18.1 . . . 10-28.1

10. Nuclear reactions and ionizing radiation (continued)

Item No.	Quantity	Symbol	Definition	Remarks
10-18.1 (10-15.1)	total linear stopping power	S, S_l	For an ionizing charged particle of energy E moving in the x-direction $S = -\mathrm{d}E/\mathrm{d}x$	Also called stopping power. Both collision losses and radiation losses are included. The ratio of the total linear stopping power of a substance to that of a reference substance is called relative linear stopping power. See also 10-54.1.
10-19.1 (10-16.1)	total atomic stopping power	S_a	$S_a = S/n$ where n is the number density of atoms in the substance.	
10-20.1 (10-17.1)	total mass stopping power	S/ϱ, (S_m)	The total linear stopping power divided by the mass density of the substance.	The ratio of the total mass stopping power of a substance to that of a reference substance is called relative mass stopping power.
10-21.1 (10-19.1)	mean linear range	R, R_l	The distance that a particle penetrates in a given substance under specified conditions averaged over a group of particles having the same energy.	
10-22.1 (10-20.1)	mean mass range	R_ϱ, (R_m)	The mean linear range multiplied by the mass density of the substance.	
10-23.1 (10-21.1)	linear ionization by a particle	N_{il}	The number of elementary charges of one sign produced over an element of length of the path of an ionizing charged particle, divided by that element.	Ionization due to secondary ionizing particles etc. is included.
10-24.1 (10-22.1)	total ionization by a particle	N_i	The total number of elementary charges of one sign produced by an ionizing charged particle along its entire path.	This quantity is dimensionless. $N_i = \int N_{il}\,\mathrm{d}l$ See remark to 10-23.1.
10-25.1 (10-23.1)	average energy loss per ion pair formed, (average energy loss per elementary charge of one sign produced)	W_i	The initial kinetic energy of an ionizing charged particle, divided by the total ionization by that particle.	The quantity S_l/N_{il}, sometimes called average energy per ion pair formed, should not be confused with W_i.
10-26.1 (10-24.1)	mobility	μ	The average drift velocity imparted to a charged particle in a medium by an electric field, divided by the field strength.	
10-27.1 (10-25.1)	ion number density, ion density	n^+, n^-	The number of positive or negative ions in a volume element, divided by that element.	n is the general symbol for number density of particles.
10-28.1 (10-26.1)	recombination coefficient	α	Coefficient in the law of recombination $-\frac{\mathrm{d}n^+}{\mathrm{d}t} = -\frac{\mathrm{d}n^-}{\mathrm{d}t} = \alpha n^+ n^-$	

10. Nuclear reactions and ionizing radiations (continued)

Units
10-18.a . . . 10-28.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
10-18.a	joule per metre	J/m			
10-18.b	electronvolt per metre	eV/m		1 eV/m = 1,602 189 2 $\times 10^{-19}$ J/m	
10-19.a	joule square metre	$J \cdot m^2$			
10-19.b	electronvolt square metre	$eV \cdot m^2$		1 $eV \cdot m^2$ = 1,602 189 2 $\times 10^{-19}$ $J \cdot m^2$	
10-20.a	joule square metre per kilogram	$J \cdot m^2/kg$			
10-20.b	electronvolt square metre per kilogram	$eV \cdot m^2/kg$		1 $eV \cdot m^2/kg$ = 1,602 189 2 $\times 10^{-19}$ $J \cdot m^2/kg$	
10-21.a	metre	m			
10-22.a	kilogram per square metre	kg/m^2			
10-23.a	reciprocal metre, metre to the power minus one	m^{-1}			
10-25.a	joule	J			
10-25.b	electronvolt	eV		1 eV = 1,602 189 2 $\times 10^{-19}$ J	
10-26.a	square metre per volt second	$m^2/(V \cdot s)$			
10-27.a	reciprocal cubic metre, metre to the power minus three	m^{-3}			
10-28.a	cubic metre per second	m^3/s			