International Standard ISO 31/13

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Quantities and units of solid state physics

Grandeurs et unités de la physique de l'état solide

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 31/13 was developed by Technical Committee ISO/TC 12, *Quantities, units, symbols, conversion factors and conversion tables.*

This second edition was submitted directly to the ISO Council, in accordance with clause 5.10.1 of part 1 of the Directives for the technical work of ISO. It cancels and replaces the first edition (i.e. ISO 31/13-1975), which had been approved by the member bodies of the following countries :

Australia	Germany, F.R.	South Africa, Rep. of
Austria	Hungary	Spain
Belgium	India	Sweden
Bulgaria	Israel	Switzerland
Canada	Mexico	Turkey
Czechoslovakia	Netherlands	United Kingdom
Denmark	New Zealand	USA
Finland	Norway	USSR
France	Romania	Yugoslavia

No member body had expressed disapproval of the document.

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Quantities and units of solid state physics

Introduction

This document, containing a table of *quantities and units of solid state physics*, is part 13 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.

(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.

Solid state physics

Quantities
13-1.1 . . . 13-7

13. Solid state physics

Item No.	Quantity	Symbol	Definition	Remarks
13-1.1	lattice vector	$\boldsymbol{R}$, $\boldsymbol{R}_0$, $\boldsymbol{T}$	A translation vector which maps the crystal lattice on itself.	
13-1.2	fundamental lattice vector	$\boldsymbol{a}_1$, $\boldsymbol{a}_2$, $\boldsymbol{a}_3$ $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{c}$	Fundamental translation vectors for the crystal lattice.	$\boldsymbol{R} = n_1\boldsymbol{a}_1 + n_2\boldsymbol{a}_2 + n_3\boldsymbol{a}_3$ where n_1, n_2 and n_3 are integers.
13-2.1	(circular) reciprocal lattice vector	$\boldsymbol{G}$	A vector whose scalar products with all lattice vectors are integral multiples of 2π.	
13-2.2	fundamental reciprocal lattice vectors	$\boldsymbol{b}_1$, $\boldsymbol{b}_2$, $\boldsymbol{b}_3$ $\boldsymbol{a}^\star$, $\boldsymbol{b}^\star$, $\boldsymbol{c}^\star$	The fundamental translation vectors for the reciprocal lattice.	$\boldsymbol{a}_i \cdot \boldsymbol{b}_k = 2\pi\delta_{ik}$ In crystallography, however, $\boldsymbol{a}_i \cdot \boldsymbol{b}_k = \delta_{ik}$ is commonly used.
13-3	lattice plane spacing	d	Distance between successive lattice planes.	
13-4	Bragg angle	θ	$2d \sin\theta = n\lambda$ where λ is the wavelength of the radiation in question and n is an integer.	In ISO 31, plane angle is regarded as dimensionless. See ISO 31/1, 1-1.1 and the introduction.
13-5	order of reflexion	n		This quantity is dimensionless.
13-6.1	short range order parameter	σ	The fraction of nearest neighbour atom pairs in an Ising ferromagnet having parallel magnetic moments minus the fraction having anti-parallel magnetic moments.	These quantities are dimensionless. Similar definitions apply to other order-disorder phenomena.
13-6.2	long range order parameter	s	The fraction of atoms in an Ising ferromagnet having their magnetic moments directed in one direction minus the fraction with magnetic moments in the opposite direction.	
13-7	Burgers vector	$\boldsymbol{b}$	Vector characterizing a dislocation, being the closing vector of a Burgers circuit encircling a dislocation line.	

13. Solid state physics

Units
13-1.a . . . 13-7.b

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
13-1.a	metre	m			
13-1.b	ångström	Å	1 Å = 10^{-10} m	1 Å = 10^{-10} m (exactly)	1 Å = 0,1 nm The use of the nanometre is recommended.
13-2.a	reciprocal metre, metre to the power minus one	m^{-1}			
13-2.b	reciprocal ångström, ångström to the power minus one	$Å^{-1}$		1 $Å^{-1}$ = 10^{10} m^{-1} (exactly)	1 $Å^{-1}$ = 10 nm^{-1} The use of the reciprocal nanometre is recommended.
13-3.a	metre	m			
13-3.b	ångström	Å			See remark to 13-1.b.
13-4.a	radian	rad			The radian is used here instead of the pure number 1. For other units, see ISO 31/1, 1-1.1.
13-4.b	degree	°		1° = 0,017 453 3 rad	
13-7.a	metre	m			
13-7.b	ångström	Å			See remark to 13-1.b.

Quantities
13-8.1 . . . 13-13

13. Solid state physics (continued)

Item No.	Quantity	Symbol	Definition	Remarks
13-8.1	particle position vector	$\boldsymbol{r}$, $\boldsymbol{R}$		To distinguish between electron and ion position vectors, small and capital letters are used, respectively.
13-8.2	equilibrium position vector of ion	$\boldsymbol{R}_0$		
13-8.3	displacement vector of ion	$\boldsymbol{u}$	$\boldsymbol{u} = \boldsymbol{R} - \boldsymbol{R}_0$	
13-9	Debye-Waller factor	D	Factor by which the intensity of a diffraction line is reduced because of lattice vibrations.	This quantity is dimensionless. It is sometimes expressed as $\exp(-2W)$; in Mössbauer spectroscopy it is also called f-factor and denoted by f.
13-10.1	circular wavenumber	k, q	$k = 2\pi/\lambda$ where λ is the wavelength.	The corresponding vector quantity $\boldsymbol{k}$ or $\boldsymbol{q}$ is called the propagation vector. When a distinction is needed between k and the symbol for the Boltzmann constant, k_B can be used for the latter. When a distinction is needed between k and q, q should be used for phonons and magnons, k for particles like electrons and neutrons.
13-10.2	Fermi circular wavenumber	k_F	Circular wave number of electrons in states on the Fermi sphere.	
13-10.3	Debye circular wavenumber	q_D	Cut-off circular wave number in the Debye model of the vibrational spectrum of a solid.	The methods of cut-off must be specified.
13-11	Debye circular frequency	ω_D	Cut-off circular frequency in the Debye model of the vibrational spectrum of a solid.	The method of cut-off must be specified.
13-12	Debye temperature	Θ_D	$k\,\Theta_D = \hbar\,\omega_D$ where k is the Boltzmann constant and $\hbar$ is the Planck constant divided by 2π.	$k = (1{,}380\,662 \pm 0{,}000\,044) \times 10^{-23}$ J/K(1) $\hbar = (1{,}054\,588\,7 \pm 0{,}000\,005\,7) \times 10^{-34}$ J.s(1)
13-13	spectral concentration of vibrational modes (in terms of circular frequency)	g, N_ω	The number of vibrational modes in an infinitesimal interval of circular frequency, divided by the range of that interval and by volume.	$g(\omega) = N_\omega(\omega) = \frac{dN(\omega)}{d\omega}$ where $N(\omega)$ is the total number of vibration modes with circular frequency less than ω, divided by volume.

(1) CODATA Bulletin 11 (1973).

13. Solid state physics (continued)

Units
13-8.a . . . 13-13.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
13-8.a	metre	m			
13-10.a	reciprocal metre, metre to the power minus one	m^{-1}			
13-10.b	reciprocal ångström, ångström to the power minus one	$Å^{-1}$			See remark to 13-2.b.
13-11.a	reciprocal second, second to the power minus one	s^{-1}			
13-12.a	kelvin	K			
13-13.a	second per cubic metre	s/m^3			

Quantities
13-14 . . . 13-19

13. Solid state physics (continued)

Item No.	Quantity	Symbol	Definition	Remarks
13-14	Grüneisen parameter	γ, Γ	$\gamma = \alpha_V/(\kappa\, c_V\, \varrho)$ where α_V is the cubic expansion coefficient, κ is the isothermal compressibility, c_V is the specific heat capacity at constant volume and ϱ is the mass density.	This quantity is dimensionless.
13-15	Madelung constant	α	For a uni-univalent ionic crystal of specified structure, the electrostatic energy per pair of ions is $$\alpha \cdot \frac{e^2}{4\pi\, \epsilon_0\, a}$$ where e is the elementary charge, ϵ_0 is the permittivity of vacuum and a is a lattice constant which should be specified.	This quantity is dimensionless.
13-16.1	mean free path of phonons	l_{ph}, Λ		
13-16.2	mean free path of electrons	l, l_e		
13-17	density of states	N_E, ϱ	The number of one-electron states in an infinitesimal interval of energy, divided by the range of that interval and by volume.	$\varrho(E) = N(E) = \frac{\mathrm{d}N(E)}{\mathrm{d}(E)}$ where $N(E)$ is the total number of electron states with energy less than E, divided by volume.
13-18	residual resistivity	ϱ_R	For metals, the extrapolated resistivity at zero thermodynamic temperature.	
13-19	Lorenz coefficient	L	$L = \lambda / \sigma T$ where λ is the thermal conductivity, σ is the electric conductivity and T is the thermodynamic temperature.	

13. **Solid state physics** (continued)

Units
13-16.a . . . 13-19.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
13-16.a	metre	m			
13-17.a	reciprocal joule reciprocal cubic metre, joule to the power minus one metre to the power minus three	$J^{-1} \cdot m^{-3}$			
13-17.b	reciprocal electronvolt reciprocal cubic metre, electronvolt to the power minus one metre to the power minus three	$eV^{-1} \cdot m^{-3}$		$1\ eV^{-1} \cdot m^{-3} = 6{,}241\ 46 \times 10^{18}\ J^{-1} \cdot m^{-3}$	See ISO 31/3, 3-24.c.
13-18.a	ohm metre	$\Omega \cdot m$			
13-19.a	volt squared per kelvin squared	V^2/K^2			