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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/XIII was drawn up by Technical Committee ISO/TC 12, *Quantities, units, symbols, conversion factors and conversion tables,* and circulated to the Member Bodies in September 1974.

It has been approved by the Member Bodies of the following countries:

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

No Member Body 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 the thirteenth part 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 introduction — General principles concerning quantities, units and symbols.*

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

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

Part III : *Quantities and units of mechanics.*

Part IV : *Quantities and units of heat.*

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

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

Part VII : *Quantities and units of acoustics.*

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

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

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

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

Part XII : *Dimensionless parameters.*

Part XIII : *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.

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.

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.

Tables of units

Units for the corresponding quantities are given together with the international symbols and the definitions.

The units are arranged in the following way :

1) The SI units are placed above broken lines and are given in large print. 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 explicitly mentioned.

For further information, see part 0.

2) 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.

3) Non-SI units which may be used temporarily together with SI units are given in small print.

1) When two types of sloping letters exist (for example as with θ, ϑ; φ, ϕ; and g, g) only one of these is given. This does not mean that the other is not equally acceptable.

4) Non-SI units which should not be used together with SI units are given in some parts of ISO 31. They are arranged in three groups :

a) *CGS-units with special names*

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

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

c) *Other units*

These are given for information, especially regarding the conversion factor. The use of those units marked with † is deprecated.

Number of digits in numerical statements

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, 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, the word 'exactly' is added.

Numbers in the column 'Remarks' are given to a precision appropriate to the particular case.

Special remarks

In each part of ISO 31 a consistent set of fundamental constants is used. In this document, the set used is presented in CODATA Bulletin 11 (December 1973).

In this document, the constants given are derived from

Planck constant :
$h = [6{,}626\ 176 \pm 0{,}000\ 036] \times 10^{-34}$ J·s

and the elementary charge :
$e = [1{,}602\ 189\ 2 \pm 0{,}000\ 004\ 6] \times 10^{-19}$ C

Solid state physics

13. Solid state physics

Quantities
13-1.1 . . . 13-7

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	$\boldsymbol{b}_1, \boldsymbol{b}_2, \boldsymbol{b}_3$ $\boldsymbol{a}^*, \boldsymbol{b}^*, \boldsymbol{c}^*$	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 part I, 1-1.1
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 antiparallel 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

Item No.	Name of unit and in certain cases abbreviation for this name	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	m^{-1}			
13-2.b	reciprocal ångström	$Å^{-1}$		$1\ Å^{-1} = 10^{10}\ m^{-1}$ (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
13-4.b	degree	°		$1° = 0{,}017\ 453\ 3$ rad	For other units, see part I, 1-1.1
13-7.a	metre	m			
13-7.b	ångström	Å			See remark to 13-1.b

13. Solid state physics (continued)

Item No.	Quantity	Symbol	Definition	Remarks
13-8.1	particle position vector	r, R		To distinguish between electron and ion position vectors, small and capital letters are used, respectively
13-8.2	equilibrium position vector of ion	R_0		
13-8.3	displacement vector of ion	u	$u = R - R_0$	
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 wave number	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 wave number	k_F	Circular wave number of electrons in states on the Fermi sphere	
13-10.3	Debye circular wave number	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	
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

Item No.	Name of unit and in certain cases abbreviation for this name	International symbol for unit	Definition	Conversion factors	Remarks
13-8.a	metre	m			
13-10.a	reciprocal metre	m^{-1}			
13-10.b	reciprocal ångström	$Å^{-1}$			See remark to 13-2.b
13-11.a	reciprocal second	s^{-1}			
13-12.a	kelvin	K			
13-13.a	second per cubic metre	s/m^3			

Item No.	Quantity	Symbol	Definition	Remarks
13-14	Grüneisen parameter	γ, Γ	$\gamma = \alpha/(\kappa\, c_V\, \rho)$ where α 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 an ionic crystal of specified structure, the electrostatic energy per atom 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 13-16.2	mean free path of phonons mean free path of electrons	l_{ph}, Λ 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	$\rho(E) = N(E) = \frac{dN(E)}{d(E)}$ 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	

Item No.	Name of unit and in certain cases abbreviation for this name	International symbol for unit	Definition	Conversion factors	Remarks
13-16.a	metre	m			
13-17.a	reciprocal joule reciprocal cubic metre	$J^{-1} \cdot m^{-3}$			
13-17.b	reciprocal electronvolt reciprocal cubic metre	$eV^{-1} \cdot m^{-3}$		$1\ eV^{-1} \cdot m^{-3} = 6{,}241\,46 \times 10^{18}\ J^{-1} \cdot m^{-3}$	
13-18.a	ohm metre	$\Omega \cdot m$			
13-19.a	volt squared per kelvin squared	V^2/K^2			

13. Solid state physics (continued)

Item No.	Quantity	Symbol	Definition	Remarks
13-20	Hall coefficient	A_H, R_H	In an isotropic conductor, the relation between electric field strength $\boldsymbol{E}$ and current density $\boldsymbol{J}$ is $\boldsymbol{E} = \rho \boldsymbol{J} + R_H (\boldsymbol{B} \times \boldsymbol{J})$ where ρ is the resistivity and $\boldsymbol{B}$ is the magnetic flux density	
13-21	thermoelectromotive force between substances a and b	E_{ab}		The positive direction for E_{ab} is from substance a to substance b at the cold junction
13-22	Seebeck coefficient for substances a and b	S_{ab}, ϵ_{ab}	$S_{ab} = \frac{dE_{ab}}{dT}$ where T is the temperature of the hot junction	$S_{ab} = S_a - S_b$ where S_a is the Seebeck coefficient of substance a
13-23	Peltier coefficient for substances a and b	Π_{ab}	Peltier heat power developed at a junction divided by electric current from substance a to substance b	$\Pi_{ab} = \Pi_a - \Pi_b$ where Π_a is the Peltier coefficient of substance a
13-24	Thomson coefficient	μ, τ	Thomson heat power developed divided by electric current and temperature difference	μ is positive if heat is developed when the temperature decreases in the direction of the electric current
13-25	work function	Φ	Energy difference between an electron at rest at infinity and an electron at the Fermi level in the interior of a substance	The contact potential difference between substances a and b is $V_a - V_b = (\Phi_b - \Phi_a)/e$ where e is the elementary charge
13-26	Richardson constant	A	The thermionic emission current density J from a metal is $J = AT^2 \exp(-\Phi/kT)$ where T is the thermodynamic temperature, k is the Boltzmann constant and Φ is the work function	

13. Solid state physics (continued)

Item No.	Name of unit and in certain cases abbreviation for this name	International symbol for unit	Definition	Conversion factors	Remarks
13-20.a	cubic metre per coulomb	m^3/C			
13-21.a	volt	V			
13-22.a	volt per kelvin	V/K			
13-23.a	volt	V			
13-24.a	volt per kelvin	V/K			
13-25.a	joule	J			
13-25.b	electronvolt	eV		$1\ eV = 1{,}602\ 19 \times 10^{-19}\ J$	
13-26.a	ampere per square metre kelvin squared	$A/(m^2 \cdot K^2)$			

Quantities
13-27.1 . . . 13-31

Item No.	Quantity	Symbol	Definition	Remarks
13-27.1	Fermi energy	E_F, ϵ_F	In a metal, the highest energy of occupied states at zero thermodynamic temperature	At $T = 0$, E_F is equal to the chemical potential per electron
13-27.2	gap energy	E_g	Difference in energy between lowest level of conduction band and highest level of valence band	
13-27.3	donor ionization energy	E_d		
13-27.4	acceptor ionization energy	E_a		
13-28	Fermi temperature	T_F	$T_F = E_F/k$ where k is the Boltzmann constant	
13-29.1	electron number density	n, n_n, n_-	Number density of electrons in conduction band	In general, subscripts n and p or − and + are used to denote electrons and holes, respectively.
13-29.2	hole number density	p, n_p, n_+	Number density of holes in valence band	n_n and n_p are also used for electron number densities in n-type and p-type regions of a $p-n$ junction respectively
13-29.3	intrinsic number density	n_i	$n\,p = n_i^2$	
13-29.4	donor number density	n_d, N_d	Number density of donor levels	
13-29.5	acceptor number density	n_a, N_a	Number density of acceptor levels	
13-30	effective mass	m^*		m_n^* and m_p^* for electrons and holes in semiconductors
13-31	mobility ratio	b	$b = \mu_n/\mu_p$ where μ_n and μ_p are the mobilities of electrons and holes respectively	This quantity is dimensionless For mobility, see part X, 10-24.1

Item No.	Name of unit and in certain cases abbreviation for this name	International symbol for unit	Definition	Conversion factors	Remarks
13-27.a	joule	J			
13-27.b	electronvolt	eV		$1\ eV = 1{,}602\ 19 \times 10^{-19}\ J$	
13-28.a	kelvin	K			
13-29.a	reciprocal cubic metre	m^{-3}			
13-30.a	kilogram	kg			

Quantities
13-32.1 . . . 13-36.3

Item No.	Quantity	Symbol	Definition	Remarks
13-32.1	relaxation time	τ	Time constant for exponential decay towards equilibrium	For electrons in metals, $\tau = l/v_F$ where l is the mean free path and v_F is the velocity of electrons on the Fermi sphere
13-32.2	carrier life time	τ, τ_n, τ_p	Time constant for recombination or trapping of minority charge carriers in semiconductors	See remark 13-29.1
13-33	diffusion length	L, L_n, L_p	$L = \sqrt{D\tau}$ where D is the diffusion coefficient and τ is the life time	See remark 13-29.1 For D, see part VIII, 8-36.1
13-34	exchange integral	J	Interaction energy arising from electron exchange	
13-35.1	Curie temperature	T_C	Critical temperature of a ferromagnet	T_C (or, in case of ambiguity, T_{Cr}) is used for critical temperature in general
13-35.2	Néel temperature	T_N	Critical temperature of an antiferromagnet	
13-35.3	Superconductor transition temperature	T_c	Critical temperature of a superconductor	
13-36.1	thermodynamic critical field strength	H_c	$G_n - G_s = \frac{1}{2}\mu_0 H_c^2 \cdot V$ where G_n and G_s are the Gibbs free energies at zero magnetic field of normal conductor and superconductor respectively, μ_0 is the permeability of vacuum and V is the volume	In type I superconductors, H_c is the critical field strength for disappearance of superconductivity
13-36.2	lower critical field strength	H_{c1}	For type II superconductors, the threshold magnetic field strength for magnetic flux entering the superconductor	The symbol H_{c3} is used for the critical field strength for disappearance of surface superconductivity
13-36.3	upper critical field strength	H_{c2}	For type II superconductors, the threshold magnetic strength for disappearance of bulk superconductivity	For the corresponding Gaussian quantities, see part V