SOLID STATE PHYSICS

Structure and Properties of Materials

Third Edition

M. A. Wahab

Alpha Science

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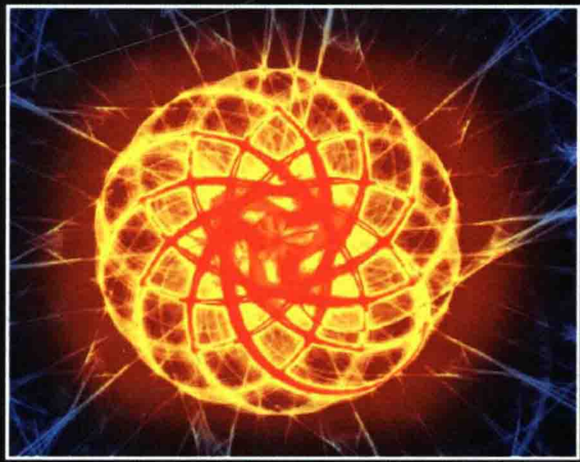

Solid State Physics, a comprehensive study for the undergraduate and postgraduate students of pure and applied sciences, and engineering disciplines is divided into eighteen chapters. The First seven chapters deal with structure related aspects such as lattice and crystal structures, bonding, packing and diffusion of atoms followed by imperfections and lattice vibrations. Chapter eight deals mainly with experimental methods of determining structures of given materials. While the next nine chapters cover various physical properties of crystalline solids, the last chapter deals with the anisotropic properties of materials. This chapter has been added for benefit of readers to understand the crystal properties (anisotropic) in terms of some simple mathematical formulations such as tensor and matrix.

KEY FEATURES:

- Simple and Coherent Text
- Solved Examples
- Brief Summary and definitions of important terms in each chapter
- Chapter on Anisotropic Properties of Materials

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Preface to the Third Edition

I am grateful to the readers for the encouraging response to the second edition. Based on their suggestions, revisions have been made in this third edition.

The whole book can be conveniently divided into two parts, the structural part and the properties part. A number of physical properties of materials have been discussed in Chapters 9 to 17. In general, they can be understood in terms of tensors of different rank. Consequently, it was felt desirable to add a new chapter at the end in the form of *anisotropic properties of materials.* The concept of tensor has been introduced to visualize the inherent macroscopic symmetries of physical properties. It has been observed that the number of property tensor decreases with the increase of crystal symmetry. This chapter has been added for the benefit of readers to understand the crystal properties (anisotropic) in terms of some simple mathematical formulations such as tensor and matrix.

Any omissions, errors, suggestions brought to the knowledge of the author will be gratefully acknowledged.

M A Wahab

Preface to the First Edition

This book intended as a textbook for B.Sc. (H) and M.Sc. (General) courses in Solid State Physics will also be helpful to the students of Chemistry, Materials Science, Engineering and those appearing for National Eligibility Test (NET) conducted by UGC/CSIR.

The present work is the outcome of lectures delivered by the author to the undergraduate and postgraduate students during the last 23 years. The aim of the book is to provide a comprehensive introduction to the subject of Solid State Physics to the students related to the above mentioned areas. In preparation of the text, the author has taken special care to present the topics in a coherent, simple and straightforward manner. This book contains a total of eighteen chapters and broadly deals with the topics related to structural aspects and various physical properties of crystalline solids. The chapter number eight particularly deals with the experimental methods to determine the crystal structures of materials. On the other hand, the chapter number eighteen deals with the anisotropic properties of materials and their representations in terms of tensors of different types and ranks. MKS (SI) system of units has been used throughout this book. Assuming that the students are familiar with vector quantities, the use of arrow sign ($\rightarrow$) on the top of them has been avoided except on the unit vectors. The main features are:

1. Solved examples for a better understanding of the text,
2. Brief summary at the end of each chapter for a quick review,
3. Definitions of important terms at the end of each chapter for further enrichment of knowledge,
4. Problems and exercises.

Although proper care has been taken during the preparation and proofreading of the manuscript, still some errors are expected to creep in. Any omissions, errors and suggestions brought to the knowledge of the author will be gratefully acknowledged.

I sincerely express my deep sense of gratitude to my Research Guide, Professor G.C. Trigunayat, Department of Physics, Delhi University from whom I have learnt a lot including the art of writing and I would like to thank my colleagues from Departments of Physics, Chemistry and Mechanical Engineering and friends for their valuable suggestion and encouragement during the preparation of the manuscript.

I am indeed grateful to all the authors and publishers of Books and Journals mentioned in the bibliography for freely consulting them and even borrowing some ideas during the preparation of the manuscript. I am also grateful to M/s Narosa Publishing House, New Delhi, for the timely publication of this book.

My special thanks to Mr. Ghayasuddin and Mr. Salahuddin for preparing the diagrams in the shortest possible time. Last, but not the least, my family members who continuously supported and encouraged me during the entire writing period. I particularly thank my daughter Dr. Shadma Wahab for helping me in proofreading of the entire manuscript.

M A Wahab

Units of Measurements

Quantity	SI UNITS		Other Units
	Written as	Read as	
Temperature	K	kelvin	°C, °F
Pressure	MPa or MNm^{-2}	Megapascal meganewton per square meter	atmosphere, Psi kg/cm^2, $dyne/cm^2$ mm of Hg
Internal energy, E			
External energy, PV			
Enthalpy, H			
Enthalpy of formation, ΔH_F	$Jmol^{-4}$	joule per mole	cal/mol
Gibbs Free energy, G			
Thermal energy, RT			
Activation Energy, Q			
Entropy, S			
Specific heat, C_v, C_p	$Jmol^{-1}k^{-1}$	joule per mole per kelvin	cal/mol/°C cal/gm/°C
Frequency of radiatition, shear strain rate, ν	s^{-1} or Hz	Hertz or per second	—
Electron energy level			
Kinetic Energy, E			
Fermi energy, E_F	J	Joule	eV, erg
Energy gap, E_g			
Contact potential, eV_0			
Ionization potential			
Electron affinity	$kJmol^{-1}$	kilo joule per mole	eV/atom, kcal/mole
Bond energy			
Lattice parameter, a			
Atomic diameter, Interplanar spacing, d			

Quantity	SI UNITS		Other Units
	Written as	Read as	
Wavelength of radiation, λ Bond length, Jump distance, δ	mm	nanometer	Å
Dipole moment	Cm	coulomb meter	debye
Density	kgm^{-3}	kilogram per cubic meter	g/cm^3 1b/cu.in.
Dislocation density, ρ	mm^{-3} or m^{-2}	meter per cubic-meter, or per square-meter	per square inch
Dislocation energy, E	Jm^{-1}	joule per meter	erg/cm eV/plane
Shear modulus, μ Young's modulus, Y	GNm^{-2}	giganewton per square meter	$dyne/cm^2$ psi
Energy of surface imperfection, γ	J/m^2	joule per square meter	erg/cm^2
Surface tension, γ	Nm^{-1}	newton per meter	dyne/cm
Flux, J	$mol\ m^{-2}\ s^{-1}$	mole per square meter per second	no. of atoms/ cm^2/s
Concentration, c	$mol\ m^{-3}$	mole per cubic meter	no. of atoms/ cm^3
Concentration of electrons and holes, n_c or n_h	m^{-3}	per cubic meter	—
Mobility, μ_c or μ_h	$m^2V^{-1}s^{-1}$	meter squared per volt per second	—
Concentration gradient, (dc/dx)	$mol\ m^{-4}$	mole per cubic meter per meter	no. of atoms/ cm^4
Diffusion coefficient, D Diffusion constant, D_0	$m^2\text{-}s^{-1}$	square meter per second	—
Vibration frequency, ν or ν' Strain rate, $\dot{\varepsilon}$	s^{-1}	per second	—
Strain energy, ε	Jm^{-3}	Joule per cubic meter	erg/cm^{-3}

Interatomic force, F Applied force	N	newton	kgf, lb, dyne
Uniaxial stress, σ and Shear stress	MNm^{-2} or MP_a	Meganewton per square meter or mega pascal	kgf/mm^2, psi $dyne/cm^2$
Current density, J	Am^{-2}	ampere per square meter	mA/cm^2
Electrical conductivity, σ	$\Omega^{-1}m^{-1}$	per ohm per meter	mho/cm
Standard electrode potential, V	V	volt	—
Capacitance, C	F or CV^{-1}	farad or coulomb per volt	—
Dielectric constant of free space, ε_0	Fm^{-1}	farad per meter	—
Polarization, P Saturation Pol., P_0	Cm^{-2}	coulomb per square meter	—
Collision time, τ	s	second	—
Dislocation velocity, v_d Drift velocity, v_d	ms^{-1}	meter per second	—
Field gradient, ε Electric field strength, E	Vm^{-1}	volt per meter	—
Resistivity, ρ	ohm m	ohm meter	$\mu\Omega$-inch. ohm-cm
Wave number, k	m^{-1}	per meter	—
Magnetic Induction, B	Wm^{-2}	weber per square meter	gauss
Magnetic field strength, H Coercieve field, H_c Magnetization, M	Am^{-1}	ampere per meter	oersted
Magnetic Permeability	Hm^{-1}	oersted	
Magnetic Permeability	Hm^{-1}	henery per meter	—
Magnetic moment, μ_m	Am^2	ampere meter squared	—

BASE UNITS

Quantity	Unit	Symbol
Length, L	metre	m
Mass, M	kilogram	kg
Time, t	second	s
Electric current, I	ampere	A
Temperature, T	kelvin	K
Amount of substance, n	mole	mol
Luminous Intensity	candela	cd

SUPPLEMENTARY UNITS

Plane angle, θ	radian	rad
Solid angle, Ω	steradian	sr

DERIVED UNITS

Quantity	Special name	Symbol	Equivalence in	
			Other derived units	Base units
Frequency	hertz	Hz	—	s^{-1}
Force, weight	newton	N	—	$kg\ ms^{-2}$
Stress, strength, & pressure	pascal	Pa	—	$kgm^{-1}s^{-2}$
Energy, work, quantity of heat	joule	J	Nm	kgm^2s^{-2}
Power	watt	W	Js^{-1}	kgm^2s^{-3}
Electric charge	coulomb	C	—	As
Electric potential	volt	V	WA^{-1}	$kgm^2s^{-3}A^{-1}$
Resistance	ohm	Ω	VA^{-1}	$kgm^2s^{-3}A^{-2}$
Capacitance	farad	F	CV^{-1}	$kg^{-1}m^{-2}s^4A^2$
Magnetic flux	weber	Wb	Vs	$kgm^2s^{-2}A^{-1}$
Magnetic flux density	tesla	T	Wbm^{-2}	$kgs^{-2}A^{-1}$
Inductance	henry	H	WbA^{-1}	$kgm^2s^{-2}A^{-2}$

PREFIX, MULTIPLES AND SUBMULTIPLES

Factors by which the unit is multiplied	Name	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	Kilo	k
10^{2}	hecto	h
10^{1}	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

Physical Constants

Avogadro's number	$N = 6.023 \times 10^{23}$ mol^{-1} $= 6.023 \times 10^{26}$ kmol^{-1}
Boltzmann's constant	$k = 1.380 \times 10^{-23}$ JK^{-1} $= 8.614 \times 10^{-5}$ eVK^{-1}
Gas constant	$R = 8.314$ Jmol^{-1}K^{-1} $= 1.987$ cal mol^{-1}K^{-1}
Plank's constant	$h = 6.626 \times 10^{-34}$ Js $= 6.626 \times 10^{-27}$ ergs
Electronic charge	$e = 1.602 \times 10^{-19}$ C $= 4.8 \times 10^{10}$ esu
Electron rest mass	$m_o = 9.11 \times 10^{-31}$kg $= 9.11 \times 10^{-28}$ g
Proton rest mass	$m_p = 1.673 \times 10^{-27}$ kg $= 1.673 \times 10^{-24}$ g
Neutron rest mass	$M_n = 1.675 \times 10^{-27}$ kg $= 1.675 \times 10^{-24}$ g
Velocity of light	$c = 2.998 \times 10^{8}$ ms^{-1} $= 2.998 \times 10^{10}$ cms^{-1}
Bohr magneton (magnetic moment)	$\mu_B = 9.273 \times 10^{-24}$ Am^2 $= 9.273 \times 10^{-21}$ erg. gauss^{-1}
Permitivity of free space	$\varepsilon_o = 8.854 \times 10^{-12}$ Fm^{-1}
Coulomb force constant	$1/4\pi\varepsilon_o = 9 \times 10^{-9}$ Nm^{2}C^{-2}
Permeability of free space	$\mu_o =$ lesu $= 4\pi \times 10^{-7}$ Hm^{-1} $= 1.257 \times 10^{-6}$ Hm^{-1}
Faraday's constant	$F = 96.49$ kC mol^{-1} (of electrons)
Atomic mass unit (amu)	$(1/10^3N) = 1.660 \times 10^{-27}$ kg
Acceleration due to gravity	$g = 9.81$ ms^{-2}
Ice point	$0°C = 273.15K$