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Rudolf P. Huebener

Conductors, Semiconductors, Superconductors

An Introduction to Solid State Physics

Second Edition

Springer

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Preface to the Second Edition

The second edition is an extended reprint of the first edition. In many chapters, a more detailed mathematical treatment of the various subjects is given. A section dealing with magnetic impurities and the Kondo effect has been added.

The author is grateful to Silvia Haindl and to Vladimir Kresin for detailed suggestions about expanding the book.

Tübingen Rudolf P. Huebener

Preface

Only a few scientific–technical developments from the last century have affected our lives in such a powerful way as the spectacular advances in our knowledge of the electronic properties of solids. Many of the present achievements are intimately connected with these advances. To name only a few: the transistor and its extreme miniaturization in microelectronics, the electronic processing of data and highly developed and powerful computers, the mobile telephone and satellite communication, television and entertainment electronics, as well as numerous instruments and systems of medical technology.

In the final analysis, the theater of all these events of dramatic progress is the world of electrons in crystals, where the (quantized) vibrations of the crystal lattice continuously demonstrate their influence. The revolutionary advances in knowledge are due to many individual people. Frequently, a true paradigm change has been necessary in order to arrange and order the new perceptions properly. Hence, it is not surprising that, as a rule, the pioneers of these new ideas initially had to overcome great difficulties and rejection, before the new concepts slowly gained acceptance. Also, in certain cases, highly focused research in large industrial laboratories turned out to be the key to success. This is impressively illustrated in particular by the invention of the transistor in the American Bell Laboratories.

This book represents an updated and strongly extended edition of the book published by the same author nearly 10 years ago with the title *Electrons in Action.* In particular, the physical contents were pointed out more clearly by mathematically formulating the fundamentals. The book is aiming at students of the natural sciences, and in particular of physics and materials science, as well as at engineers, as an introduction to solid-state physics. It may serve as a motivating prestage and companion of the established and very detailed textbooks.

In addition to the physical contents, the book treats the important role played by many famous and often still very young scientists. The fundamental developments are supplemented by describing their scientific and historic environment.

Marius Orlowski, Virginia Polytechnic Institute, provided important advice.

Tübingen Rudolf P. Huebener
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Contents

Mathematical Symbols

a	Distance between the neighboring atoms or building blocks of the crystal lattice
e	Electric elementary charge
f	Spring constant
$\mathbf{f}_L$	Lorentz force
h	Hour
h	Planck's constant
$\hbar$	$h/2\pi$
j	Electrical current density
j_s	Supercurrent density
k	Wave number = $2\pi/\lambda$
$\mathbf{k}$	Wave vector = $k_X + k_Y + k_Z$
k_Z	Component of the wave vector in z-direction
$\mathbf{k}_F$	Fermi wave vector
k_B	Boltzmann's constant
ℓ	Mean free path
$m = m_e$	Electron mass
m_h	Mass of the holes
m_c	Cyclotron mass of the electrons
n	Electron concentration
n_s	Density of the superconducting electrons
p	Hole concentration
$\mathbf{r}$	Lattice vector
$\mathbf{r}$	Electron coordinate
t	Time
v_D	Drift velocity
v_F	Fermi velocity
z	Figure of merit
mA	Milliampère
mg	Milligram
nm	Nanometer = 10^{-9} m

μm	Micrometer = 10^{-6} m
eV	Electron volt (energy unit)
A	Vector potential
B	Magnetic flux density
C_V	Specific heat at constant volume
D_2	Density of states in the two-dimensional case
D_e	Density of states per volume
E	Energy
F	Free energy
E	Electric field
G	Vector in the reciprocal lattice
G	Density of the Gibbs free energy
G_o	Quantized unit of the electrical conductance
GeV	Gigaelectron volt = 10^9 eV
GHz	Gigahertz = 10^9 per second
H	Magnetic field
H_C	Critical magnetic field of a superconductor
H_C	Coercive field
H_{C1}	Lower critical magnetic field of a superconductor
H_{C2}	Upper critical magnetic field of a superconductor
I	Electrical current
I_r	Recombination current
I_g	Generation current
I_C	Critical electrical current density of a superconductor
J	Exchange integral
K	Kelvin
K	Wave vector of the phonons
L	Lorenz number
L	Orbital angular momentum
M	Magnetization
N	Number of the crystal atoms
R	Electrical resistance
R_H	Hall constant
S	Seebeck coefficient
S	Spin angular momentum
S_m	Mixing entropy
T	Temperature
T_C	Critical temperature of a superconductor
T_D	Debye temperature = $h\nu_D/k_B$
T_{CU}	Curie temperature
THz	Terahertz = 10^{12} per second
U	Total vibrational energy of a crystal
U	Inner energy
V	Electrical voltage
V	Volume

α	Polarizability
α	Madelung constant
δ	Scattering angle
κ	Heat conductivity
κ_e	Heat conductivity of the electrons
κ_G	Heat conductivity of the crystal lattice
θ	Debye temperature
ε	Electron energy
ε_F	Fermi energy
λ	Wave length
λ_m	Magnetic penetration depth of superconductors
μ	Magnetic moment
μ_o	Permeability of vacuum
μ_B	Bohr magneton
η	Damping coefficient of the motion of magnetic flux quanta
ω	Angular frequency
ω_B	Bloch frequency
ω_c	Cyclotron angular frequency
ω_D	Debye angular frequency
ω_L	Larmor frequency
ν	Frequency
$\nu_c = \omega_c/2\pi$	Cyclotron frequency
$\nu_D = \omega_D/2\pi$	Debye frequency
ν_E	Einstein frequency
χ	Magnetic susceptibility
χ_p	Paramagnetic susceptibility
τ	Mean collision time
ξ	Coherence length of a superconductor
$\boldsymbol{\rho}$	Lattice vector
ρ_f	Flux-flow resistivity
σ	Electrical conductivity
φ	Phase of a wave function
$\boldsymbol{\varphi}_o$	Magnetic flux quantum
φ_0	Atomic wave function
ψ	Wave function of the superconducting Cooper pairs
Π	Peltier coefficient