

DE GRUYTER

Vladimir V. Kiselev

COLLECTIVE EFFECTS IN CONDENSED MATTER PHYSICS

STUDIES IN MATHEMATICAL PHYSICS 44

DE
—
G



Vladimir V. Kiselev

Collective Effects in Condensed Matter Physics

DE GRUYTER

Mathematics Subject Classification 2010
82D, 81V80, 74B

Author

Dr. Sci. (Phys.-Math.) Vladimir V. Kiselev
Russian Academy of Sciences
M. N. Mikheev Institute of Metal Physics
Sophia Kovalevskaya str., 18
620108 Yekaterinburg
kiseliev@imp.uran.ru

ISBN 978-3-11-058509-4
e-ISBN (PDF) 978-3-11-058618-3
e-ISBN (EPUB) 978-3-11-058513-1
ISSN 2194-3532

Library of Congress Control Number: 2018934560

Bibliographic information published by the Deutsche Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie;
detailed bibliographic data are available on the Internet at <http://dnb.dnb.de>.

© 2018 Walter de Gruyter GmbH, Berlin/Boston
Typesetting: le-tex publishing services GmbH, Leipzig
Printing and binding: CPI books GmbH, Leck

www.degruyter.com



Contents

Foreword — V

Prefactory Notes — X

1	Electrons and Holes in Metals and Semiconductors — 1
1.1	Electrons in Crystalline Solids: The Formulation of a Simplified Single Particle Model — 1
1.2	The Theoretical Description of the Periodic Structure of Crystals — 3
1.3	A Reciprocal Lattice and the First Brillouin Zone — 7
1.4	Energy Levels of an Electron in a Periodic Potential and Bloch's Theorem — 10
1.5	Electrons in a Weak Periodic Field — 22
1.6	The Fermi Energy, Surface, Temperature, and Thermal Layer for a Gas of Free Electrons — 35
1.7	Method of Constructing the Fermi Surface of a Weak Potential: The Second and Subsequent Brillouin Zones — 40
1.8	Electronic Specific Heat of Normal Metals — 44
1.9	Screening of the Coulomb Field of External Electric Charges in Metals (the Thomas–Fermi Model) and Semiconductors — 53
1.10	Plasmons and Dynamic Screening of the Electron-Electron Interactions in Metals — 57
1.11	The Pauli Principle and Suppression of Electron-Electron Collisions in Metals — 61
1.12	The Concept of the Mean Free Path of Electrons: Electrical and Thermal Conductivities of Metals and the Wiedemann–Franz law — 63
1.13	The Semiclassical Dynamics of Electrons in a Crystal — 71
1.14	The Justification of Semiclassical Equations of Motion, the Hamiltonian Formulation and Liouville's Theorem — 74
1.15	The Lack of Contribution of Bands Completely Filled with Electrons to an Electric Current and a Flux of Heat — 77
1.16	Holes — 78
1.17	Semiclassical Motion of Electrons in a Crystal in Constant Electric and Magnetic Fields — 83
1.18	General Properties of Semiconductors: the Concentration of Electrons and Holes and the Law of Mass Action — 90
1.19	Intrinsic Semiconductors — 96
1.20	Impurity Levels — 97
1.21	Concentrations of Charge Carriers and the Chemical Potential of Impurity Semiconductors — 101

- 1.22 The Electrical Conductivity of Semiconductors — 107
- 1.23 Rectifying Action of a p - n Junction and a Simplified Calculation of the Current Voltage Characteristics of a Diode — 109
- 2 Crystal Lattice Vibrations — 118**
- 2.1 The Dynamics of the Crystal Lattice in the Harmonic Approximation — 118
- 2.2 General Properties of the Force Constants — 122
- 2.3 The Born–Karman Boundary Conditions – the Dynamic Matrix of a Crystal — 124
- 2.4 Properties of the Dynamic Matrix — 125
- 2.5 The Normal Modes of Lattice Vibrations — 126
- 2.6 Goldstone’s Theorem – Acoustic and Optical Modes of the Normal Vibrations of a Crystal — 132
- 2.7 Lattice Vibrations Using an Example of a Linear Chain of Atoms — 135
- 2.8 A Diatomic Chain: A One-Dimensional Lattice with Basis — 139
- 2.9 Quantum Theory of the Harmonic Crystal — 143
- 2.10 The Debye Interpolation Theory of the Heat Capacity of a Crystal — 145
- 2.11 The Role of the Anharmonic Terms in the Energy of a Crystal — 148
- 2.12 Electron-Phonon Interaction — 151
- 3 Superconductivity — 154**
- 3.1 The Basic Physical Properties of Superconductors — 154
- 3.2 The Qualitative Features of the Microscopic Theory — 159
- 3.3 The Second Order Correction to the Energy of a Two Electron System Due to Electron-Phonon Interaction — 162
- 3.4 *Cooper Pairs* — 166
- 3.5 The Bardeen–Cooper–Schrieffer Theory (*Qualitative Results*) — 170
- 3.6 The Ginzburg–Landau Theory – The London Penetration Depth — 174
- 3.7 Quantization of a Magnetic Flux — 177
- 3.8 *The Microscopic Nature of Two Types of Superconductors* – Vortex Lattices and Superconducting Magnets — 178
- 3.9 Possible Physical Mechanisms of High Temperature Conductivity — 182
- 3.10 High Temperature Superconductors — 185
- 4 Quantum Coherent Optics: Interaction of Radiation with Matter — 191**
- 4.1 Maxwell’s Equations and Natural Oscillations of an Electromagnetic Field in a Closed Cavity — 191
- 4.2 Quantization of a Free Electromagnetic Field — 198
- 4.3 Zero point Energy — 203

- 4.4 Amplitude and Phase Operators for Single-Mode Quantum States of a Radiation Field — **204**
- 4.5 Coherent Photon States: Their Properties and Relationship with Classical Electromagnetic Waves — **207**
- 4.6 Equilibrium Thermal Radiation and Its Properties — **211**
- 4.7 The Einstein Coefficients: Spontaneous and Induced Energy Transitions of an Atomic System Under an Electromagnetic Field — **217**
- 4.8 Interaction Between a Quantized Electromagnetic Field and a Two Level Atom – the Electric Dipole Approximation — **220**
- 4.9 The Rates of Spontaneous and Induced Atomic Transitions When Electromagnetic Waves Travel through a Medium as Well as Under Thermal Radiation Conditions — **225**
- 4.10 Absorption and Amplification of Directed Plane-Parallel Flux by Matter — **238**
- 4.11 The Concept of Time and Spatial Dispersions of a Medium — **242**
- 4.12 Intrinsic Oscillations of Optical Laser — **249**
- 4.13 A Pulsed Ruby Laser — **252**
- 4.14 Heterolasers — **255**
- 4.15 Formalism of the Density Matrix and Semiclassical Theory of the Propagation of Electromagnetic Waves in a Two Level Atom Medium — **259**
- 4.16 Self-Induced Transparency and the Concept of Strongly Nonlinear Particle-like Excitations (Solitons) — **265**

- 5 Dislocations and Martensitic Transitions — 278**
- 5.1 Ordered Macroscopic States of a Crystal and a Nonlinear Theory of Elasticity — **278**
- 5.2 Dislocations in a Crystal — **286**
- 5.3 Basic Equations of the Theory of Dislocations — **296**
- 5.4 Interaction of Dislocations with a Stress Field — **312**
- 5.5 An Expansion in Multipole Moments of Fields Created by Dislocation Systems — **317**
- 5.6 The Peierls Model of a Dislocation Core — **326**
- 5.7 Weakly Nonlinear Soliton-like Excitations in a Two-Dimensional Martensitic Transition Model — **335**

Exercises — 345

Bibliography — 357

Index — 361