# Contents

# Preface

# 1 Classification of Solids

- 1.1 Introduction 1
- 1.2 Physical Properties of Solids 2
  - A Ionic Crystals 4
  - B Covalent (Homopolar) Crystals 9
  - C Metallic Crystals 11
  - D Molecular Crystals 12
- 1.3 Crystal Symmetry 13

# 2 Lattice Vibrations and Lattice Specific Heat

- 2.1 Introduction 23
- 2.2 Monatomic Linear Chain 24
- 2.3 Diatomic Linear Chain 30
- 2.4 Lattice Vibrations in Three Dimensions 33
- 2.5 Reciprocal Lattice 35
- 2.6 Transition to Quantum Mechanics 38

2.7 Specific Heat of Solids 39 A Einstein's Theory 40 B Debye's Theory 43

#### 3 Equilibrium Properties of a Free-electron Gas

- 3.1 Introduction 54
- 3.2 Free-electron Gas 55
- 3.3 Limit of Extreme Degeneracy 59
- 3.4 Classical Limit 61
- 3.5 Electronic Specific Heat 63
- 3.6 Electronic Spin Paramagnetism 67

## 4 Electrons in a Periodic Lattice

- 4.1 Introduction 75
- 4.2 Many-particle Problem 76
- 4.3 Bloch Theorem 79
- 4.4 One-dimensional Crystal 81
- 4.5 Approximation of Nearly Free Electrons 87
- 4.6 Tight-binding Approximation 90
- 4.7 Cellular (Wigner-Seitz) Method 98
- 4.8 Velocity and Acceleration of Electrons in Solids 101
- 4.9 Relationship between Various Physical Properties and the Effective Mass 103

## 5 Transport Equation

- 5.1 Introduction 108
- 5.2 Boltzmann Equation 110
- 5.3 Solution of Bloch Equation. Relaxation-time Approximation 114
- 5.4 Justification of Relaxation Time in the Bloch Equation 121
- 5.5 Variational Solution of the Transport Equation 130

#### 6 Relaxation Mechanisms

- 6.1 Introduction 137
- 6.2 Stationary Crystal Imperfections: Classification and Description 138
  - A Planar Imperfections 138
  - B Linear Imperfections 138
  - C Point Imperfections 142
  - D Disorder 142
- 6.3 Lattice Vibrations 145
- 6.4 Scattering of Electrons by Imperfections 146
- 6.5 Phonon-induced Transitions: Metals 147
- 6.6 Scattering by Stationary Imperfections: Metals 154
  - A Point Imperfections 154
  - B Scattering by Dislocations; the Deformation Potential 158
  - C Scattering by Planar Imperfections; Stacking Faults 159
- 6.7 Scattering of Charge Carriers in Semiconductors 162
- 6.8 Calculation of Lattice Scattering in Semiconductors 170
  - A Acoustic Modes 170
  - B Interaction of Electrons with Optical Modes; Polar Crystals 170
- 6.9 Impurity Scattering in Semiconductors 173

- A Impurity Energy Levels 173
- B Scattering of Electrons (or Holes) by Ionized Impurities 178
- C Scattering by Neutral Impurities 179
- D Scattering by Dislocations 179

## 7 Conductivity and Related Phenomena: Metals

- 7.1 Introduction 182
- 7.2 Electrical Conductivity 183
  A Resistivity due to Lattice Scattering 183
  B Residual Resistivity 196
- 7.3 Thermal Conductivity 202
- 7.4 Thermoelectric Effects; Phonon Drag 207
- 7.5 Conduction in a Magnetic Field 216
  - A Hall Effect 217
  - **B** Magnetoresistance 221
  - C Thermomagnetic Effects 224
- 7.6 Electrical Properties of Ferromagnetic Metals 226
- 7.7 Electron-Electron Scattering: Metals 232
- 7.8 Size Effects; Thin Films and Wires 235

## 8 Homogeneous Semiconductors

- 8.1 Introduction 244
- 8.2 Semiconductor Statistics 246 A Intrinsic Regime 246
  - B Extrinsic Regime 249
- 8.3 Mobility and Conductivity 254
  - A Lattice-scattering Regime 255
  - B Impurity-scattering Regime 266
  - C Carrier-Carrier Scattering 269
  - D Temperature Dependence of Mobility and Conductivity 272
- 8.4 Piezoresistance 280
- 8.5 Magnetoresistance and the Hall Effect 286
  - A Ideal Semiconductor 286
  - B Multivalley Semiconductors 300
- 8.6 Thermal Conductivity and Thermoelectric Power 303
  - A Thermal Conductivity 303
  - B Thermoelectric Power 305
- 8.7 Devices Using Homogeneous Semiconductors 309
  - A Thermistor 309
  - B Varistor 309
  - C Hall-effect Devices 310
  - D Thermoelectric Devices 311

## 9 Rectifying Junctions and Transistors

- 9.1 Introduction 317
- 9.2 Equilibrium Conditions in Inhomogeneous Semiconductors 318 A Diffusion Currents 318
  - **B** Recombination Mechanisms 319
- 9.3 Barrier Rectification 322
  - A Metal-Semiconductor Junctions 322

- *B* Semiconductor *p*-*n* Junctions 324
- C Tunnel Diodes 328
- 9.4 Transistors 330
  - A n-p-n Transistor 330
  - B n-p-i-n Transistor 334

# 10 Optical Properties of Semiconductors

- 10.1 Introduction 335
- 10.2 Free-carrier Absorption 336
  - A Long-wavelength Limit 338
  - B Short-wavelength Limit 339
- 10.3 Fundamental Absorption 341
  - A Direct (Vertical) Transitions 343
  - B Indirect (Nonvertical) Transitions 345
- 10.4 Exciton Absorption 351
- 10.5 Photoelectric Effects 353
  - A Photoconduction 353
  - B Photovoltaic Effect 358
  - C Photomagnetic (PEM) Effect 359
  - D Photoelectric Effects at p-n Junctions 361

## 11 Properties of Semiconductors and Metals in Strong Magnetic Fields

- 11.1 Introduction 370
- 11.2 High-field Effects in Semiconductors 371
  - A Cyclotron Resonance 372
  - B Interband Magnetooptic (IMO) Effects 379
- 11.3 High-field Effects in Metals 385
  - A De Haas-van Alphen (HA) Effect 391
  - B Cyclotron (Az'bel-Kaner) Resonance 399
  - C Ultrasonic Resonances 400
  - D Transport Properties 402

## Appendix A Summary of Elementary Quantum Mechanics

- A.1 Basic Postulates and the Schroedinger Equation 407
- A.2 Free Particles and the One-dimensional Potential Well 412
- A.3 One-dimensional Harmonic Oscillator 414
- A.4 Charged Particles in a Uniform Magnetic Field 415
- A.5 Stationary Perturbation Theory 416
- A.6 Time-dependent Perturbation Theory 418
- Appendix B Units and Conversion Factors
- Appendix C The Periodic Table
- Appendix D Values of Important Physical Constants and Some Convenient Conversion Factors
- Appendix E List of Symbols
- Index 435