

# CONTENTS

<i>Preface</i> . . . . .	v
<i>Contributors to this Treatise</i> . . . . .	vii

## VOLUME 1

<b>1. Early Experiments and Phenomenological Theories</b> . . . . .	<b>1</b>
B. S. CHANDRASEKHAR	
I. Introduction . . . . .	1
II. Experimental Properties . . . . .	5
III. Phenomenological Theories . . . . .	19
General References . . . . .	46
References . . . . .	46
<b>2. The Theory of Bardeen, Cooper, and Schrieffer</b> . . . . .	<b>51</b>
G. RICKAYZEN	
I. Introduction . . . . .	52
II. A Normal Fermi Liquid . . . . .	55
III. Cooper's Problem . . . . .	58
IV. Reduced Hamiltonian . . . . .	62
V. Self-Consistent Solution . . . . .	63
VI. Criterion for Superconductivity . . . . .	68
VII. Critical Temperature . . . . .	69
VIII. Energy Gap . . . . .	73
IX. Excitation Spectrum . . . . .	76
X: Thermodynamic Functions . . . . .	77
XI. Wave Function . . . . .	80
XII. Complete Hamiltonian . . . . .	82
XIII. Spin Susceptibility of the Electrons . . . . .	85
XIV. Effects of Transverse Electromagnetic Fields . . . . .	88
XV. Meissner Effect and Penetration Depth . . . . .	90
XVI. Effects of Varying Transverse Electromagnetic Fields . . . . .	95

XVII. Infinite Conductivity . . . . . 97  
 XVIII. Ultrasonic Attenuation . . . . . 100  
 XIX. Thermal Conductivity of the Electrons . . . . . 102  
 XX. Tunneling of Electrons . . . . . 106  
 XXI. Nuclear Spin Relaxation Time . . . . . 109  
 XXII. Conclusions . . . . . 111  
 References . . . . . 112

**3. Equilibrium Properties: Comparison of Experimental Results with Predictions of the BCS Theory . . . . . 117**

R. MESERVEY and B. B. SCHWARTZ

I. Introduction . . . . . 118  
 II. BCS Interaction and Pairing . . . . . 119  
 III. Density of States by Tunneling Measurements . . . . . 132  
 IV. Thermodynamic Properties . . . . . 158  
 V. Electrodynamic Properties . . . . . 171  
 VI. Conclusions . . . . . 183  
 References . . . . . 184

**4. Nonequilibrium Properties: Comparison of Experimental Results with Predictions of the BCS Theory . . . . . 193**

D. M. GINSBERG and L. C. HEBEL

I. Introduction . . . . . 194  
 II. Basic Interactions . . . . . 196  
 III. Coherence Effects in Transition Probabilities, Absorption Coefficients, and Relaxation Rates . . . . . 198  
 IV. Electromagnetic Absorption . . . . . 203  
 V. Ultrasonic Attenuation . . . . . 221  
 VI. Thermal Conductivity . . . . . 229  
 VII. Nuclear Spin Relaxation . . . . . 233  
 VIII. Notes Added in Proof . . . . . 249  
 References . . . . . 252

**5. The Green's Function Method . . . . . 259**

VINAY AMBEGAOKAR

I. Properties of Green's Functions . . . . . 259  
 II. Green's Functions of a Superconductor . . . . . 282  
 III. Thermodynamic Properties . . . . . 303  
 IV. Absorption of Energy . . . . . 307  
 V. Effects of Impurities . . . . . 310  
 References . . . . . 319

**6. The Ginzburg-Landau Equations and Their Extensions . . . . . 321**

N. R. WERTHAMER

I. Phenomenological Approach . . . . . 321  
 II. Gor'kov's Derivation from Microscopic Theory . . . . . 328  
 III. Extensions of the Ginzburg-Landau Equations . . . . . 341  
 IV. Time-Dependent Ginzburg-Landau Equations . . . . . 363  
 References . . . . . 369

**7. Collective Modes in Superconductors . . . . . 371**

PAUL C. MARTIN

I. Introduction . . . . . 371  
 II. Collective Motions of the Excitations . . . . . 375  
 III. Exciton-like Modes . . . . . 384  
 References . . . . . 390

**8. Macroscopic Quantum Phenomena . . . . . 393**

JAMES E. MERCEREAU

I. Introduction . . . . . 393  
 II. Quantized Behavior of Superconductors . . . . . 395  
 III. Josephson Quantum-Phase Detector . . . . . 398  
 IV. Superconducting Interferometers . . . . . 403  
 V. Experiments Utilizing Superconducting Interferometers . . . . . 413  
 VI. Dynamics of the Macroscopic Quantum System . . . . . 417  
 References . . . . . 420

**9. Weakly Coupled Superconductors . . . . . 423**

B. D. JOSEPHSON

I. Introduction . . . . . 423  
 II. Microscopic Theory of the Current through a Weak Link . . . . . 426  
 III. Macroscopic Equations for Tunneling Barriers . . . . . 437  
 IV. Properties of Weakly Coupled Superconductors . . . . . 441  
 References . . . . . 447

**10. The Electron-Phonon Interaction and Strong-Coupling Superconductors . . . . . 449**

DOUGLAS J. SCALAPINO

I. Introduction . . . . . 449

II. Theory of Nearly Free Electron Metals . . . . .	455
III. Electron Self-Energy of a Strong-Coupling Superconductor . . . . .	485
IV. Properties of Strong-Coupling Superconductors . . . . .	522
References . . . . .	558
<b>11. Tunneling and Strong-Coupling Superconductivity . . . . .</b>	<b>561</b>
W. L. McMILLAN and J. M. ROWELL	
I. Historical Introduction . . . . .	561
II. Theory of Superconductivity . . . . .	566
III. Theory of Tunneling . . . . .	573
IV. Experiment . . . . .	583
V. Inverting the Gap Equation . . . . .	593
VI. Results . . . . .	595
VII. Conclusions . . . . .	611
References . . . . .	611
<b>12. Superconductivity in Low-Carrier-Density Systems: Degenerate Semiconductors . . . . .</b>	<b>615</b>
MARVIN L. COHEN	
I. Introduction . . . . .	615
II. Theory . . . . .	619
III. Some Properties of Low-Carrier-Density Superconductors . . . . .	648
IV. Speculations, Summary, and Discussion . . . . .	658
References . . . . .	663

## VOLUME 2

<b>13. Superconductivity in the Transition Metals: Theory and Experiment . . . . .</b>	<b>665</b>
G. GLADSTONE, M. A. JENSEN and J. R. SCHRIEFFER	
I. Introduction . . . . .	666
II. Energy Band Structure . . . . .	668
III. Electron-Electron Interactions in the Normal State . . . . .	682
IV. Pairing Interaction and the Energy Gap Equation . . . . .	706
V. Superconducting Transition Temperature . . . . .	731
VI. Properties of the Superconducting State . . . . .	777
VII. Conclusions . . . . .	806
References . . . . .	807

<b>14. Theory of Type II Superconductors . . . . .</b>	<b>817</b>
ALEXANDER L. FETTER and PIERRE C. HOHENBERG	
I. Introduction . . . . .	818
II. Surface Energy . . . . .	819
III. Abrikosov's Solution of the Ginzburg-Landau Equations . . . . .	828
IV. Extensions of the Abrikosov Theory . . . . .	864
V. Density of Electronic States . . . . .	887
VI. Specific Heat in the Mixed State . . . . .	898
VII. Transport Properties . . . . .	903
Appendixes . . . . .	905
References . . . . .	920
<b>15. Type II Superconductors: Experiments . . . . .</b>	<b>925</b>
BERNARD SERIN	
I. Introduction . . . . .	925
II. Early Developments . . . . .	928
III. Ginzburg-Landau Parameters . . . . .	930
IV. Arrangement and Properties of Fluxoids . . . . .	953
V. Thin Films in Transverse Magnetic Fields . . . . .	963
VI. Aspects of Surface Superconductivity . . . . .	969
References . . . . .	973
<b>16. Boundary Effects and Small Specimens . . . . .</b>	<b>977</b>
J. P. BURGER and D. SAINT-JAMES	
I. Introduction . . . . .	977
II. Equilibrium Properties . . . . .	979
III. Nonequilibrium Properties: Metastable States . . . . .	998
References . . . . .	1003
<b>17. Proximity Effects . . . . .</b>	<b>1005</b>
G. DEUTSCHER and P. G. DE GENNES	
I. Introduction . . . . .	1005
II. Transition Temperature of an N-S Layer in Zero Field . . . . .	1008
III. Excitation Spectrum of an N-S Layer in Zero Field . . . . .	1016
IV. Proximity Effects under Magnetic Fields . . . . .	1022
V. Conclusions . . . . .	1032
References . . . . .	1033

**18. Gapless Superconductivity . . . . . 1035**

KAZUMI MAKI

I. Introduction . . . . . 1036  
 II. Time-Reversal Symmetry. . . . . 1038  
 III. Superconducting Alloys Containing Magnetic Impurities . . . . . 1044  
 IV. Thermodynamics . . . . . 1049  
 V. Transport Properties . . . . . 1058  
 VI. Superconducting Films in Magnetic Fields. . . . . 1067  
 VII. Superconductors with Spatially Varying Order Parameter . . . . . 1079  
 Appendix: Theory of a Pure Type II Superconductor in the High-Field Region . . . . . 1094  
 References . . . . . 1102

**19. Flux Flow and Irreversible Effects . . . . . 1107**

Y. B. KIM and M. J. STEPHEN

I. Introduction . . . . . 1107  
 II. Local Model of a Vortex Line . . . . . 1111  
 III. Experiments on Flux Flow . . . . . 1114  
 IV. Forces on Vortex Lines . . . . . 1128  
 V. Voltages in the Mixed State . . . . . 1132  
 VI. Flow Pattern Due to a Single Vortex Line. . . . . 1133  
 VII. Hall Effect . . . . . 1138  
 VIII. Thermomagnetic and Galvanomagnetic Effects . . . . . 1141  
 IX. Critical-State Model . . . . . 1145  
 X. Flux Creep. . . . . 1149  
 XI. Instabilities: Flux Jumps. . . . . 1156  
 References . . . . . 1162

**20. A Comparison of the Properties of Superconductors and Superfluid Helium . . . . . 1167**

W. F. VINEN

I. Introduction . . . . . 1168  
 II. Properties of Superfluid Helium. . . . . 1168  
 III. Bose Superfluid Compared with the Uncharged BCS Superfluid . . . . . 1184  
 IV. Comparison with Superconductors . . . . . 1202  
 V. Specific Problems . . . . . 1212  
 VI. Conclusions . . . . . 1231  
 References . . . . . 1232

**21. The Intermediate State in Type I Superconductors . . . . . 1235**

J. D. LIVINGSTON and W. DESORBO

I. Introduction . . . . . 1235  
 II. Theory . . . . . 1236  
 III. Direct Observations of Field Distribution . . . . . 1244  
 IV. Properties . . . . . 1268  
 V. Relation between the Mixed and Intermediate States. . . . . 1274  
 VI. Conclusions . . . . . 1275  
 References . . . . . 1278

**22. Superconducting Devices . . . . . 1283**

V. L. NEWHOUSE

I. Introduction . . . . . 1284  
 II. High-Field Magnets . . . . . 1284  
 III. Flux Pumps, Dynamos, and Motors . . . . . 1295  
 IV. Cryotrons . . . . . 1303  
 V. Computer Storage Elements . . . . . 1315  
 VI. Measuring Instruments . . . . . 1322  
 VII. Microwave Devices . . . . . 1336  
 References . . . . . 1339

**23. Superconductivity in the Past and the Future . . . . . 1343**

P. W. ANDERSON

A Critical Summary . . . . . 1343  
 References . . . . . 1357

**Appendix A: Second Quantization. . . . . 1359**

VINAY AMBEGAOKAR

*Author Index* . . . . . 1367

*Subject Index* . . . . . 1391