

Contents

Preface to the Third Edition IX

Introduction 1

References 9

1	Fundamental Properties of Superconductors	11
1.1	The Vanishing of the Electrical Resistance	11
1.2	Ideal Diamagnetism, Flux Lines, and Flux Quantization	21
1.3	Flux Quantization in a Superconducting Ring	30
1.4	Superconductivity: A Macroscopic Quantum Phenomenon	33
1.5	Quantum Interference	45
1.5.1	Josephson Currents	47
1.5.2	Quantum Interference in a Magnetic Field	59
	References	71
2	Superconducting Elements, Alloys, and Compounds	75
2.1	Introductory Remarks	75
2.1.1	Discovery, Preparation, and Characterization of New Superconductors	75
2.1.2	Conventional and Unconventional Superconductors	76
2.2	Superconducting Elements	78
2.3	Superconducting Alloys and Metallic Compounds	83
2.3.1	The β -Tungsten Structure	84
2.3.2	Magnesium Diboride	86
2.3.3	Metal-Hydrogen Systems	87
2.4	Fullerides	88
2.5	Chevrel Phases and Boron Carbides	89
2.6	Heavy-Fermion Superconductors	92
2.7	Natural and Artificial Layered Superconductors	94
2.8	The Superconducting Oxides	96
2.8.1	Cuprates	96
2.8.2	Bismuthates, Ruthenates, and Other Oxide Superconductors	103
2.9	Iron Pnictides and Related Compounds	104

2.10	Organic Superconductors	107
2.11	Superconductivity at Interfaces	110
	References	111
3	Cooper Pairing	117
3.1	Conventional Superconductivity	117
3.1.1	Cooper Pairing by Means of Electron–Phonon Interaction	117
3.1.2	The Superconducting State, Quasiparticles, and BCS Theory	124
3.1.3	Experimental Confirmation of Fundamental Concepts about the Superconducting State	129
3.1.3.1	The Isotope Effect	130
3.1.3.2	The Energy Gap	133
3.1.4	Special Properties of Conventional Superconductors	150
3.1.4.1	Influence of Lattice Defects on Conventional Cooper Pairing	150
3.1.4.2	Influence of Paramagnetic Ions on Conventional Cooper Pairing	157
3.2	Unconventional Superconductivity	163
3.2.1	General Aspects	163
3.2.2	Cuprate Superconductors	170
3.2.3	Heavy Fermions, Ruthenates, and Other Unconventional Superconductors	186
3.2.4	FFLO-State and Multiband Superconductivity	193
	References	196
4	Thermodynamics and Thermal Properties of the Superconducting State	201
4.1	General Aspects of Thermodynamics	201
4.2	Specific Heat	205
4.3	Thermal Conductivity	209
4.4	Ginzburg–Landau Theory	212
4.5	Characteristic Lengths of the Ginzburg–Landau Theory	216
4.6	Type-I Superconductors in a Magnetic Field	221
4.6.1	Critical Field and Magnetization of Rod-Shaped Samples	221
4.6.2	Thermodynamics of the Meissner State	226
4.6.3	Critical Magnetic Field of Thin Films in a Field Parallel to the Surface	230
4.6.4	The Intermediate State	231
4.6.5	The Wall Energy	235
4.6.6	Influence of Pressure on the Superconducting State	239
4.7	Type-II Superconductors in a Magnetic Field	244
4.7.1	Magnetization Curve and Critical Fields	246
4.7.2	The Shubnikov Phase	256
4.8	Fluctuations above the Transition Temperature	268
4.9	States Outside Thermodynamic Equilibrium	272
	References	277

5	Critical Currents in Type-I and Type-II Superconductors	283
5.1	Limit of the Supercurrent Due to Pair Breaking	283
5.2	Type-I Superconductors	285
5.3	Type-II Superconductors	291
5.3.1	Ideal Type-II Superconductor	291
5.3.2	Hard Superconductors	296
5.3.2.1	Pinning of Flux Lines	296
5.3.2.2	Magnetization Curve of Hard Superconductors	301
5.3.2.3	Critical Currents and Current–Voltage Characteristics	310
	References	318
6	Josephson Junctions and Their Properties	321
6.1	Current Transport across Interfaces in a Superconductor	321
6.1.1	Superconductor–Insulator Interface	321
6.1.2	Superconductor–Normal Conductor Interfaces	328
6.1.3	Superconductor–Ferromagnet Interfaces	335
6.2	The RCSJ Model	337
6.3	Josephson Junctions under Microwave Irradiation	342
6.4	Vortices in Long Josephson Junctions	346
6.5	Quantum Properties of Superconducting Tunnel Junctions	357
6.5.1	Coulomb Blockade and Single-Electron Tunneling	358
6.5.2	Flux Quanta and Macroscopic Quantum Coherence	363
	References	368
7	Applications of Superconductivity	373
7.1	Superconducting Magnetic Coils	374
7.1.1	General Aspects	374
7.1.2	Superconducting Cables and Tapes	375
7.1.3	Coil Protection	386
7.2	Superconducting Permanent Magnets	388
7.3	Applications of Superconducting Magnets	390
7.3.1	Nuclear Magnetic Resonance	390
7.3.2	Magnetic Resonance Imaging	394
7.3.3	Particle Accelerators	395
7.3.4	Nuclear Fusion	397
7.3.5	Energy Storage Devices	398
7.3.6	Motors and Generators	401
7.3.7	Magnetic Separation and Induction Heaters	404
7.3.8	Levitated Trains	405
7.4	Superconductors for Power Transmission: Cables, Transformers, and Current Fault Limiters	406
7.4.1	Superconducting Cables	407
7.4.2	Transformers	409
7.4.3	Current Fault Limiters	411
7.5	Superconducting Resonators and Filters	412

7.5.1	High-Frequency Behavior of Superconductors	413
7.5.2	Resonators for Particle Accelerators	417
7.5.3	Resonators and Filters for Communications Technology	420
7.6	Superconducting Detectors	425
7.6.1	Sensitivity, Thermal Noise, and Environmental Noise	426
7.6.2	Incoherent Radiation and Particle Detection: Bolometers and Calorimeters	427
7.6.3	Coherent Detection and Generation of Radiation: Mixers, Local Oscillators, and Integrated Receivers	431
7.6.4	Quantum Interferometers as Magnetic Field Sensors	440
7.6.4.1	SQUID Magnetometer: Basic Concepts	440
7.6.4.2	Environmental Noise, Gradiometers, and Shielding	450
7.6.4.3	Applications of SQUIDS	454
7.7	Superconductors in Microelectronics	459
7.7.1	Voltage Standards	460
7.7.2	Digital Electronics Based on Josephson Junctions	463
	References	468

Monographs and Article Collections 477

History of Superconductivity 477

General Books 477

Special Materials 477

Tunnel Junctions, Josephson Junctions, and Vortices 477

Nonequilibrium Superconductivity 478

Applications of Superconductivity 478

General Overview 478

Magnets, Cables, Power Applications 478

Microwaves, Magnetic Field Sensors, Electronics 478

Low Temperature Physics and Technology 478

Index 479