

Contents

- 1 Introduction** 1
 - 1.1 Setting the Stage: What Is a Superfluid?..... 1
 - 1.2 Plan of the Course and Further Reading 4
 - References 5
- 2 Superfluid Helium** 7
 - 2.1 Landau’s Critical Velocity 8
 - 2.2 Thermodynamics of Superfluid Helium..... 10
 - 2.3 Two-Fluid Model..... 13
 - 2.4 First and Second Sound..... 17
 - 2.4.1 Single-Fluid Hydrodynamics..... 17
 - 2.4.2 Two-Fluid Hydrodynamics 22
 - 2.4.3 Sound Modes 25
 - References 30
- 3 Superfluidity in Quantum Field Theory**..... 33
 - 3.1 Lagrangian and Conserved Charge..... 34
 - 3.2 Spontaneous Symmetry Breaking 37
 - 3.3 Superfluid Velocity..... 40
 - 3.4 Goldstone Mode..... 43
 - 3.5 Symmetry Restoration at the Critical Temperature..... 50
 - References 52
- 4 Relativistic Two-Fluid Formalism** 53
 - 4.1 Covariant Formulation 53
 - 4.2 Relation to the Original Two-Fluid Formalism 57
 - 4.3 Connecting Field Theory with the Two-Fluid Formalism..... 59
 - 4.3.1 Goldstone Mode and Superfluid Density 61
 - 4.3.2 Generalized Pressure and Sonic Metric..... 64
 - References 66

5 Fermionic Superfluidity: Cooper Pairing	67
5.1 Derivation of the Gap Equation	69
5.1.1 Lagrangian	70
5.1.2 Mean-Field Approximation	72
5.1.3 Nambu-Gorkov Space	74
5.1.4 Gap Equation	77
5.2 Quasiparticle Excitations	79
5.3 Solving the Gap Equation	84
5.4 Examples	87
5.4.1 Electronic Superconductor	87
5.4.2 Anisotropic Superfluid	88
5.4.3 Color Superconductor	90
References	92
6 Meissner Effect in a Superconductor	93
6.1 Massive Gauge Boson	94
6.2 Meissner Mass from the One-Loop Polarization Tensor	96
6.2.1 Gauge Boson Propagator and Screening Masses	96
6.2.2 Calculation of the Meissner Mass	99
References	103
7 BCS-BEC Crossover	105
7.1 Ultra-Cold Atomic Gases	106
7.2 Crossover in the Mean-Field Approximation	110
References	119
8 Low-Energy Excitations in a Fermionic Superfluid	121
8.1 Fluctuations Around the Mean-Field Background	122
8.2 Expanding in the Fluctuations	124
8.3 Goldstone Mode and Low-Energy Expansion	129
References	135
9 Cooper Pairing with Mismatched Fermi Momenta	137
9.1 Quasiparticle Excitations	138
9.2 Free Energy	141
9.2.1 Chandrasekhar-Clogston Limit	144
9.3 Superfluids with Mismatched Charge Densities	149
References	154

Introduction to Superfluidity

Field-theoretical Approach and Applications

Schmitt, A.

2015, VIII, 155 p. 26 illus., 11 illus. in color., Softcover

ISBN: 978-3-319-07946-2