Preface

In quantum liquids the interaction between the particles leads to a variety of interesting and unusual states of condensed-matter systems, e.g. superconductivity and the fractional quantum Hall effect (FQHE) in electron systems. In this book we investigate quantum-field-theoretical approaches for interacting fermion systems. Originally, the quantum-field theory is designed as a perturbation theory to describe weakly interacting many-particle systems. For a proper treatment of interaction and correlation effects beyond the perturbation theory, the series of Feynman diagrams must be resummed partially. We present several resummation schemes which depend on the particular physical effect considered. We start with a compact description of the self-consistent quantum-field theory and the conserving approximations.

Superconductivity in fermion systems is caused by the interplay of two phenomena: formation of bound pairs by attractive interaction between the fermions and condensation of the pairs at low temperatures leading to long-range order and superfluidity. We consider a three-dimensional system of fermions with short-range attractive interaction which shows a crossover from BCS superconductivity to Bose–Einstein condensation of bound pairs if the interaction strength is tuned from weak to strong coupling. While the self-consistent version of the quantum-field theory is well suited to describe condensation of pairs and superfluidity, a second resummation leading to the Bethe–Salpeter equation describes the formation of bound pairs.

The local particle-number conservation is related to a fundamental symmetry: invariance with respect to local gauge transformations. The self-consistent quantum-field theory is gauge invariant only if all Feynman diagrams are resummed, but not if the perturbation series is truncated at finite order. Thus, by a local gauge transformation the self-consistent quantum-field theory can be modified to incorporate nonperturbative effects. We develop an approach which may be viewed as a generalized bosonization and which can be used as a perturbation theory for systems with degenerate levels.

The approach is applied to the two-dimensional electron system in a strong perpendicular magnetic field. Degeneracies are implied by the Landau-level quantization for noninteger filling factors ν so that the Coulomb interaction leads to strong correlations of the electrons at low temperatures. We calculate the spectral function $A(\epsilon)$ of the lowest Landau level and the magnetization $M(T)$ for systems in the FQHE regime. We find good agreement of our theoretical results with recent experiments. Finally, we discuss some further applications of the modified self-consistent quantum-field theory to Coulomb plasmas and to interacting boson systems.

I would like to thank Prof. Dr. W. Zwerger for many discussions from which I have learned a great deal about many-particle physics, superconductivity, bosonization, and the quantum Hall effect. I am especially grateful to Prof. Dr. A. H. MacDonald for an enjoyable collaboration at the Indiana University in Bloomington, which gave me a deep insight into the quantum Hall effect and into the American way of research. Finally, I thank Dr. M. Kasner for discussions about magnetic properties in FQHE systems.

München, February 1999 *Rudolf Haussmann*