Introduction

The understanding of new emerging unconventional ground states is a great challenge for experimental and theoretical solid-state physicists. New ground states are developing, where different energy scales compete, leading to a high sensitivity of the system to external tuning parameters like doping, pressure or magnetic field.

The exploration of superconductivity proved to be a fascinating and challenging scientific undertaking. Discovered by H. Kammerlingh Onnes in 1911, prior to the development of the quantum theory of matter, superconductivity was defying a microscopic theory for more than four decades until the BCS theory was formulated in 1957 by J. Bardeen, L. N. Cooper and J. R. Schrieffer. Superconductivity of most of the simple metals or metallic alloys is well described within the frame of the BCS scenario, however, in the last thirty years numerous new superconducting materials were found to exhibit exotic properties not accounted for by the BCS theory. Among them are included the high-T_c compounds, the heavy-fermion superconductors and as well the organic superconductors. It was the purpose of this work to probe different facets of superconductivity in heavy-fermion and in low-dimensional metallic compounds.

In the class of the heavy-fermion systems the Kondo-effect, leading to a non-magnetic ground state, competes with the Ruderman-Kittel-Kasuya-Yosida (RKKY) interactions which favors magnetic order. It is this competition which leads to unusual physical properties in proximity to a quantum critical point, where the magnetic ordering temperature is suppressed to zero. The heavy-fermion compound $CeCoIn_5$ is superconducting at atmospheric pressure having the highest superconducting transition temperature, among all Ce-based heavy-fermion systems [1]. $CeCoIn_5$ is assumed to be situated close to an antiferromagnetic quantum critical point giving rise to non-Fermi liquid behavior in the normal state [2]. Recently, the possible appearance of an inhomogeneous superconducting state in $CeCoIn_5$, called Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state, attracted much attention not only among solid state physicists [3, 4]. The FFLO state, predicted independently by Fulde and Ferrell [5] and by Larkin and Ovchinnikov [6] 40 years ago, is a spatially inhomogeneous superconducting phase, where the order parameter is periodically modulated in real space. It is predicted to appear in type-II superconductors close to the upper critical field if the orbital pair-breaking is negligible relative to the Pauli-limiting effect, in sufficiently clean systems. The theoretical concept of the FFLO state is not only of importance in solid state physics, but also in elementary-particle physics [7]. The FFLO state eluded the experimental confirmation until very recently. $CeCoIn_5$ is the first material where different physical experiments show strong evidence pointing to the realization of the FFLO state at low temperatures close to the upper critical field for superconductivity. However, the presence of strong antiferromagnetic fluctuations in this compound might be responsible for the anomaly taken as signature of the FFLO state.

The central part of the present work is the exploration of the nature of this low temperature phase observed inside the superconducting state in $CeCoIn_5$ at high magnetic fields. Using external pressure to suppress the magnetic fluctuations we were able for the first time to provide evidence that the FFLO state in $CeCoIn_5$ exists away from the influence of the strong magnetic fluctuations present at atmospheric pressure. For this purpose we developed a new type of miniature pressure cell allowing us to conduct heat capacity studies under quasi-hydrostatic pressure conditions at high magnetic fields up to $B = 14$ T and at low temperatures down to $T = 100$ mK, on precisely oriented $CeCoIn_5$ single crystals. We studied the evolution of the magnetic field – temperature phase diagram with pressure. Not only the first-order character of the transition from the normal to the superconducting state at high magnetic fields persists with increasing pressure, but we could also follow the transition from the vortex to the FFLO state for all pressures. Moreover, the FFLO region in the phase diagram is extended at high pressures. This strongly supports the genuine FFLO origin of the anomaly in the superconducting state and makes a magnetic origin very unlikely.

Despite of more than two decades of intensive experimental studies to characterize the heavy-fermion superconductor UBe_{13}, many details behind its physical properties remain undisclosed. Several experiments probing the superconducting state of this material, revealed anomalous features which are regarded as evidence for unconventional superconductivity. The most compelling evidence obtained so far for unconventional superconductivity regards the giant ultrasonic absorption anomaly observed directly below T_c [8, 9] which was ascribed to collective modes or domain-wall damping due to a multi-component order parameter [10]. Theoretical calculations by Sigrist *et al.* [11, 12] predict the behavior of a multi-component order parameter for an anisotropic superconductor under uniaxial stress. Uniaxial stress is lowering the crystal symmetry and the degeneracy in the order parameter representation might be lifted leading to a split of the superconducting transition. We performed high resolution AC specific heat experiments under uniaxial pressure up to $p = 0.55$ GPa. A small feature resembling a superconducting temperature splitting is induced by pressure. However, this feature has to be regarded carefully as, though improbable, pressure anisotropy cannot be completely ruled out as origin.

The interplay between superconductivity and a charge-density wave (CDW) instability remains an interesting experimental and theoretical challenge. The opening of a dielectric gap in the electronic spectrum due to electron-hole pairing, reduces the density of states at the Fermi-level. However, not uncommon are the examples of compounds displaying a CDW instability which at lower temperatures enter a superconducting ground state. In such cases the superconductivity sets in from a normal but gapped state. We thoroughly investigated the quasi-one-dimensional, metallic compound $Tl_xV_6S_8$ employing resistivity, specific heat and susceptibility measurements at ambient pressure for different Tl fillings. Moreover, in resistivity studies, we followed the evolution with pressure of both superconducting and CDW phases in the above mentioned compounds.

This dissertation is divided into six chapters. After this introduction, in Chapter 1 we will outline the basic theoretical concepts later needed for the analysis of the experimental results. In Chapter 2 we briefly introduce the experimental techniques with a special focus on the new pressure cells developed during this thesis and used for the measurements presented in Chapters 3 to 5. In Chapter 3 the possible realization of the inhomogeneous superconducting FFLO state in $CeCoIn_5$ is studied by specific heat measurements under hydrostatic pressure, while in Chapter 4 the results of AC specific heat experiments on UBe_{13} under uniaxial pressure are presented. The ambient pressure properties as well as results obtained by resistivity measurements under hydrostatic pressure on the one-dimensional metallic compounds $Tl_xV_6S_8$ are discussed in Chapter 5. At the end, Chapter 6 summarizes and concludes this thesis.