Abstract

Phase transitions at absolute zero in temperature are driven by quantum fluctuations and are therefore called quantum phase transitions. Their description requires a framework beyond that for finite temperature phase transitions. A second order quantum phase transition is a quantum critical point (QCP). At the QCP, quantum fluctuations are critical. This may have strong influence on the physical properties at finite temperatures, which are then called quantum critical. For metals, this becomes apparent through strong deviations from the predictions of Landau Fermi liquid (FL) theory, referred to as non-Fermi liquid (NFL) behaviour. Experimentally, quantum critical behaviour is best investigated by performing measurements at low energies (low temperatures and frequencies) because the signatures of quantum criticality are most pronounced near the QCP.

One particularly interesting group of materials in this context are heavy fermion compounds, where certain atoms with partially filled f-electron shells like Yb or Ce are constituents of the crystal structure. The f-electrons interact with the conduction electrons via the Kondo interaction, which induces a screening of the magnetic moments by the conduction electrons. They also interact with each other via the RKKY exchange interaction. External parameters like magnetic field, hydrostatic pressure, or doping can tune the relation between the two competing interactions to a critical value, where a QCP occurs.

In the course of this work, several compounds were investigated experimentally in the context of quantum criticality. Measurements were performed on the heavy fermion compounds $YbRh_2Si_2$, $Ce_3Pd_{20}Si_6$, and CeB_6, on the oxypnictide substitution series $CeNiAs_{1-x}P_xO$, and on the itinerant magnet doping series $Ti_{1-x}Sc_xAu$. All compounds order antiferromagnetically at ambient pressure, zero magnetic field, and $x = 0$. The ordering temperature was suppressed by the external parameters magnetic field ($YbRh_2Si_2$, $Ce_3Pd_{20}Si_6$, CeB_6), pressure (CeNiAsO), and doping or isoelectronic substitution ($CeNiAs_{1-x}P_xO$, $Ti_{1-x}Sc_xAu$). The influence of magnetic field as an additional tuning parameter was investigated for different substitution levels of $CeNiAs_{1-x}P_xO$.

The temperature-dependent resistivity was measured down to dilution refrigerator temperatures for all compounds; furthermore, $YbRh_2Si_2$ samples were contacted and tested for measurements at ultra-low temperatures. Magnetoresistivity and Hall resistivity were measured with magnetic field applied along different crystallographic directions in cubic $Ce_3Pd_{20}Si_6$, which showed signatures of a direction-dependent second QCP (in addition to an isotropic one at lower fields). For CeB_6, magnetic properties, specific heat, and resistivity were also measured with magnetic field applied along different crystallographic directions, and evaluated upon tuning the magnetic field towards the QCP. In $Ti_{1-x}Sc_xAu$, signatures of a QCP at $x = 13\%$ from previous resistivity measurements at higher temperatures could be confirmed at lower temperatures.

A central part of this thesis is devoted to a new microwave experiment to probe the dynamic response of quantum critical materials. In $YbRh_2Si_2$, this is of particular interest for the investigation of its Kondo breakdown energy scale, which emerges from the QCP and strongly broadens with increasing temperature. To study its electronic excitations in the vicinity of the QCP and around this energy scale, $YbRh_2Si_2$ single crystals were coupled to the microwave field of a coplanar waveguide resonator, and the changes of the resonance properties were traced within the field-temperature phase diagram of $YbRh_2Si_2$.