Non-Fermi liquid behavior in Ni–Pd

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Recently, non-Fermi liquid (NFL) phenomena were in the focus of many experimental and theoretical studies. An continuous increase of the linear term of the heat capacity down to the lowest temperatures and significant deviations from a T^2 dependence of the resistivity were classified as hallmarks of NFL behavior. In most cases reported so far, NFL behavior appears close to the phase boundary of anti-ferromagnetic (AFM) order. The largest body of experimental evidence has been presented in heavy-fermion systems (HFS), in which competing RKKY and Kondo interactions offer the opportunity to tune the systems towards vanishing magnetic order. Alloying or pressure have been used to establish a $T = 0$ K magnetic phase-transition.

We wanted to study a ferromagnetic (FM) quantum critical point (QCP) in a transition metal with marginal disorder. Quite naturally Pd, which is a strongly enhanced Pauli-paramagnet close to FM order, seems to be the ideal starting material to investigate a FM zero-temperature critical point. It is known since long that approximately 2.5% of nickel ions doped into palladium induce FM order [1]. A systematic study on heat capacity, electrical resistivity, magnetization and magnetic susceptibility in Ni–Pd alloys at ambient pressure and zero magnetic field for different nickel concentration has been reported in Ref. [2].

In this report we present experimental results on the resistivity in Ni–Pd in external magnetic fields close to the QCP. We find that already in moderate fields Fermi-liquid (FL) behavior is recovered.

Ni_xPd_{1-x} samples for concentrations $0 \leqslant x \leqslant 0.1$ were prepared from high purity (5 N) starting materials by Argon arc techniques. The samples were remelted many times and then annealed for 5 days at 1000°C. X-ray diffraction and microprobe analysis revealed single-phase materials. DC-magnetization experiments have been performed using a quantum design SQUID magnetometer to characterize the samples. The resistivity was measured for different magnetic fields up to 14 T in a He flow cryostat for temperatures $1.4\ \mathrm{K} < T < 300$ K.

The electrical resistivity was measured for a series of Ni_xPd_{1-x} samples close to the critical concentration in different external magnetic fields up to 14 T. As representative result Fig. 1 shows the resistivity ρ as a function of T^2 for the nickel concentration $x = 0.026$ which is close to the critical concentration where the FM-phase transition appears at zero temperature. While the resistivity, $\Delta\rho = \rho - \rho_0$, in zero magnetic field exactly follows the $T^{5/3}$ dependence, which is expected at a FM QCP [3,4], FL behavior is recovered in a magnetic field of

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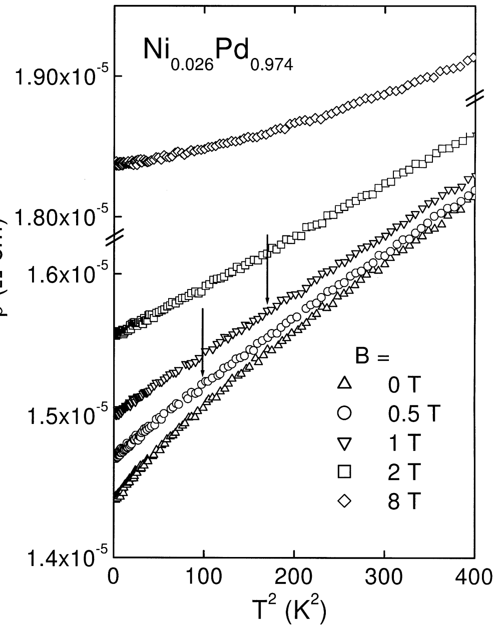

Fig. 1. The resistivity ρ is plotted versus T^2 for different magnetic fields, $B = 0$, 0.5,1,2, and 8 T at the critical concentration $x_c = 0.026$. The arrows indicate the Fermi-liquid temperature T_{FL}, characterizing the crossover from NFL to FL behavior.

2 T in the whole temperature range up to 20 K. At higher magnetic fields the resistivity increases steeper and in a magnetic field of 8 T a power law $\Delta\rho \propto T^{2.8}$ has been observed. An exponent of 2.8 was also found in the magnetically ordered samples for Ni-concentrations $0.045 \leqslant x \leqslant 0.1$ in zero magnetic field [2]. Therefore, we conclude that the sample reveals complete FM order in an external field of 8 T. The exponent of 2.8 is significantly larger than 2, caused by the additional scattering of the charge carriers by magnons. In the magnetic field region below 2 T the Fermi-liquid temperature T_{Fl} increases with increasing field. T_{FL} is determined by the validity range of the $\Delta\rho \propto T^2$ power law in the resistivity. The arrows in Fig. 1 indicate the FL temperature for magnetic fields of 0.5 T ($T_{Fl} = 9.9$ K) and 1 T ($T_{Fl} = 13.0$ K).

A schematic B, T phase diagram for $Ni_{0.026}Pd_{0.974}$ as determined from resistivity and susceptibility measurements is shown in Fig. 2. The solid lines indicate the 'phase' boundaries between the different regimes: NFL ($\Delta\rho \propto T^{5/3}$), FL ($\Delta\rho \propto T^2$), and induced FM ($\Delta\rho \propto T^{2.8}$). At high temperatures phonon scattering plays an important role for the temperature dependence of the resistivity. So far the magnetic field dependence has only been studied close to AFM quantum critical points: In $CeNi_2Ge_2$ NFL behavior is destroyed in fields of 2 T and a broad FL regime ($\Delta\rho \propto T^2$) has been detected in fields up to 15 T [5]. In $CeCu_{4.8}Ag_{1.2}$ NFL behavior has been induced in finite external fields and in even higher fields a FL has been recovered [6]. It is clear that close to a FM QCP external magnetic fields will induce ferromagnetic order. The present experiments show that at low fields and low temperatures NFL phenomena still survive. At moderate fields up to 2 T a pure FM, with $\Delta\rho \propto T^2$, is observed and it is only at higher fields that FM order is induced. Further experimental work is needed to establish quantitatively the temperature and field dependence of the phase boundaries.

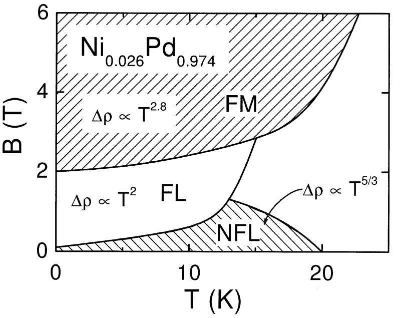

Fig. 2. Schematic B, T phase diagram for Ni–Pd as derived from resistivity measurements. The different regimes are indicated by solid lines.

In conclusion, at the QCP in Ni–Pd we studied the magnetic field and temperature dependence of the resistivity. The NFL phenomena at zero field are rapidly suppressed and followed by a FL regime and finally by a induced FM state. In near future this study will be complemented by heat capacity and susceptibility measurements.

Acknowledgements

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