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MAGNETORESISTIVITY OF HEAVY-FERMION UPt_3 IN HIGH MAGNETIC FIELDS UP TO 35 T

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The anisotropic magnetoresistivity of heavy-fermion UPt_3 has been measured in high magnetic fields up to 35 T. At 1.5 and 4.2 K the resistivity increases as function of the field for both current directions (basal plane and hexagonal axis), and attains a large maximum value if the component of the field in the basal plane equals 21 T. At 20.3 and 77 K the magnetoresistivity is negative for field directions in the basal plane.

Amongst the heavy-fermion systems, UPt_3 is the only compound that is believed to exhibit pronounced spin-fluctuation phenomena at low temperatures. Evidence for spin fluctuations is extracted mainly from a $T^3\ln(T/T^*)$-contribution to the specific heat [1–3] and the low temperature thermal expansion [4]. Further support is offered by an initially quadratic field dependence of the differential susceptibility at 4.2 K [5] and the overall temperature dependence of the electrical resistivity [6]. The latter experiment reveals that the resistivity, as function of temperature, strongly increases at low temperatures, followed by a negative curvature towards the temperature axis and a tendency to saturate at large values in the room-temperature region. The normal-state low-temperature resistivity follows a T^2-law up to approximately 2 K [6–8]. As other parameters the resistivity of hexagonal UPt_3 is strongly anisotropic, which is reflected in the coefficients of the T^2-term, i.e. 1.6 $\mu\Omega\text{cm}/\text{K}^2$ (for a current in the basal plane) and 0.7 $\mu\Omega\text{cm}/\text{K}^2$ (hexagonal axis), and in the room-temperature values 238 $\mu\Omega$cm (basal plane) and 132 $\mu\Omega$cm (hexagonal axis) as well. One of the salient features of UPt_3 for which no satisfactory explanation exists yet, is a magnetic anomaly near 21 T. This anomaly, first observed in magnetisation measurements [1,5], takes place only at low temperatures and for field directions in the basal plane. In a further investigation of this phenomenon we have studied the magnetic field dependence of the resistivity. Parts of these results have been published elsewhere [9,10].

The magnetoresistivity experiments have been performed for a current direction along the hexagonal axis, as well as for a current direction in the basal plane. In both cases the effect of a magnetic field parallel and perpendicular to the current direction has been studied.

To that purpose a single-crystalline batch of UPt_3 has been prepared in a tri-arc melting equipment by a Czochralski method. Two cylindrical samples, with typical sizes of 1.5 mm diameter and a length of 6 mm, were cut out of the bulk by means of spark erosion. The temperature dependence of the resistivity of these samples has been published before [6]. The residual resistivity values equal 6.3 $\mu\Omega$cm (a-axis) and 1.7 $\mu\Omega$cm (c-axis). Both samples showed a superconducting transition near 0.48 K [2].

Magnetic fields up to 35 T were produced in the Amsterdam High Field Installation [11]. In our case two pulse-shapes were used: (1) a pulse in which fields are kept constant for approximately 50 ms, i.e. long enough to neglect the effect of eddy currents, and (2) a pulse in which the field, after having reached 35 T, decreases at a constant rate of 56 T/s. The change in resistivity with field is measured with a standard dc-method ($I = 0.5$ A in most cases) [11]. Stable temperatures were ensured by immersing the samples directly into liquid helium, hydrogen or nitrogen. The relative accuracy is estimated to be 3%, whereas the absolute accuracy amounts to 7% due to the determination of the geometrical factor (A/l).

The experimental results for $H\|(I\|a)$ are shown in fig. 1, at temperatures indicated. Both pulse-types offered nearly identical results. Data displayed here

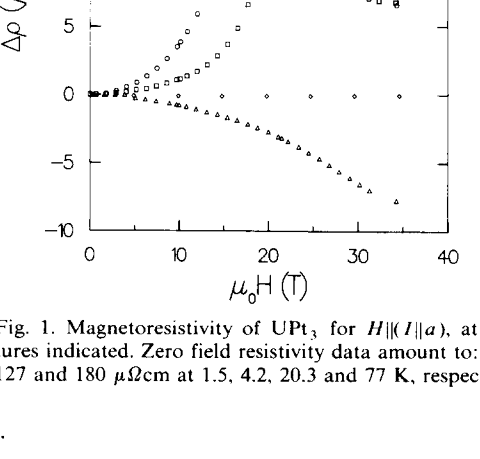

Fig. 1. Magnetoresistivity of UPt_3 for $H\|(I\|a)$, at temperatures indicated. Zero field resistivity data amount to: 9.4, 28.2, 127 and 180 $\mu\Omega$cm at 1.5, 4.2, 20.3 and 77 K, respectively.

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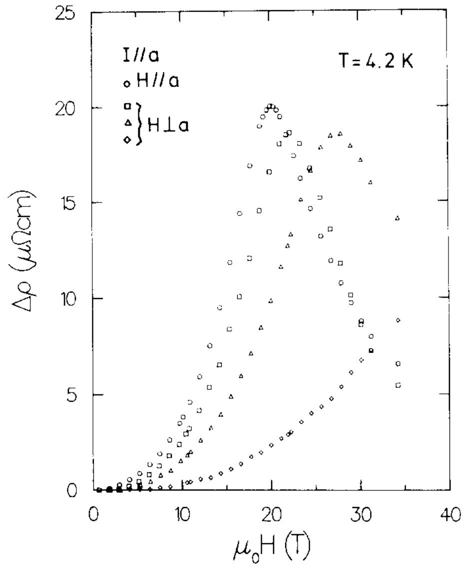

Fig. 2. Magnetoresistivity of UPt$_3$ for $H\|(I\|a)$, (○), and $H\perp(I\|a)$ at 4.2 K. Orientation of H with respect to the b-axis is (20 ± 5)° (□), (40 ± 5)° (△) and (70 ± 5)° (◇).

were obtained with the latter pulse-type (except data at 77 K). At 1.5 and 4.2 K $\Delta\rho$ is positive and has a maximum near 21 T, whereas $\Delta\rho$ is negative at 20.3 and 77 K. Fig. 2 shows once more the curve for $H\|(I\|a)$ at 4.2 K, but includes data for $H\perp(I\|a)$, for different orientations of H in the bc-plane. From fig. 2 we conclude that the maximum in the resistivity is attained for a value of the component of the field in the basal plane equal to 21 T. This result is consistent with previous data, taken at 1.5 and 4.2 K, for a current direction along the hexagonal axis [10]: for $H\perp I$ $\Delta\rho$ has a maximum at 21 T, whereas for $H\|I$ $\Delta\rho$ increases monotonically up to 2 $\mu\Omega$cm at 35 T. At 77 K the magnetoresistivity for $H\perp(I\|c)$ is slightly negative and amounts to $\Delta\rho/\rho = -0.014$ with $\rho(77\text{ K}) = 100$ $\mu\Omega$cm.

An explanation of the magnetoresistivity data at 1.5 and 4.2 K in terms of a spin-fluctuation model seems to be inappropriate, since in a magnetic field the spin-fluctuation contribution to the resistivity is expected to be depressed. If there is any negative term in the magnetoresistivity in this low-temperature region, it is completely immersed in the huge positive effect. At higher temperatures the negative $\Delta\rho$ might be indicative of spin fluctuations ($\Delta\rho \propto H^2$ at 20.3 K).

As was pointed out by Franse et al. [10], some properties of UPt$_3$ resemble crystal-field effects, as observed in hexagonal PrNi$_5$. In order to investigate whether the anomaly in $\Delta\rho$ might have its origin in crystal-field effects, we performed magnetoresistivity measurements on a single-crystalline sample of PrNi$_5$, for a current along the hexagonal axis and the field applied in the basal plane. However, no anomaly was observed. The resistivity at 4.2 K increases instead monotonically as a function of the field, from 3.0 $\mu\Omega$cm at zero field to 3.5 $\mu\Omega$cm at 35 T. At room temperature ρ amounts to 27 $\mu\Omega$cm, much lower than the corresponding value for UPt$_3$ (132 $\mu\Omega$cm). A description of the low-temperature magnetoresistivity data in terms of crystal-field effects is, therefore, unlikely.

Subsequent explanations in which the high-field anomaly has its origin in (itinerant) antiferromagnetism or band-structure effects, seem not probable, regarding the available information obtained from other experiments on UPt$_3$ [10]. It has been suggested that this remarkable magnetic field dependence of the resistivity must be ascribed to the same many-body effects that cause the anomalies in the low temperature properties [10]. More detailed experiments will be necessary to verify these hypotheses.

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