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DEPRESSION OF SPIN FLUCTUATIONS IN UPt_3 AT VERY HIGH PRESSURE

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We have measured the electrical resistivity of single-crystal whiskers of UPt_3 subjected to quasi-hydrostatic pressures as high as 200 kbar. The main effect is a strong reduction of the spin-fluctuations, evidenced by the decrease of the quadratic coefficient A of ρ versus T below 2 K. In the c direction, the observed pressure dependence of ρ indicates a steady increase of $T_{sf} \propto (1/\sqrt{A})$ by a factor of 7.5 between 0 and 200 kbar.

1. Introduction

The unusual coexistence of superconductivity and spin fluctuations in the heavy-fermion system UPt_3 has led to various speculations regarding the nature of the pairing mechanism and the symmetry of the superconducting wave functions [1]. In order to elucidate the interplay between these two, usually conflicting, phenomena, pressure has been used as an external parameter for varying the characteristic energy k_BT_{sf} of the spin-fluctuation spectrum. Measurements up to 20 kbar [2,3] had revealed an interesting correlation between the pressure dependences of T_{sf} and T_c. Since previous measurements on another heavy-fermion system, $CeCu_2Si_2$ had shown a maximum of T_c with pressure around 100 kbar [4], it seemed interesting to investigate UPt_3 also at higher pressures. In this paper, we describe the first resistivity results obtained in the normal state ($T > 1$ K).

2. Experiments

In a previous work [5], it was found than when UPt_3 is melted (e.g. in an arc furnace), whiskers grow spontaneously out of the melt at fast cooling. The c axis of the hexagonal structure is always parallel to the needle axis. Most of the whiskers have a well developed surface corresponding to a given crystallographic plane, and their cross-section is almost an equilaterial trapezium. Such specimens are ideally suited for experiments between Bridgman anvils [4]. The measurements at high pressure were performed on one whisker with dimensions approximately equal to $0.8 \times 0.09 \times 0.01$ mm^3. Another one was used for the ambient pressure experiment. Both samples were studied in the unannealed state.

3. Results and discussion

The electrical resistance of UPt_3 was measured at 12 different pressures, with the current direction along the c axis. A selected set of curves is displayed in fig. 1 ($0 \leq P \leq 202$ kbar).

The room-temperature (RT) resistance varies very little below 60 kbar, in agreement with earlier results obtained at lower pressures [2,3]. The R–T curves for $P = 1$ bar and 21.5 kbar were therefore normalized at 300 K to the same absolute resistivity value of 132 $\mu\Omega$cm quoted in ref. [6], and the geometrical factor l/s was then assumed to remain constant at higher pressures [4]. R(295 K) is seen to decrease by about 15% between 0 and 200 kbar.

At low temperatures, the residual resistivities $\rho_0(P)$

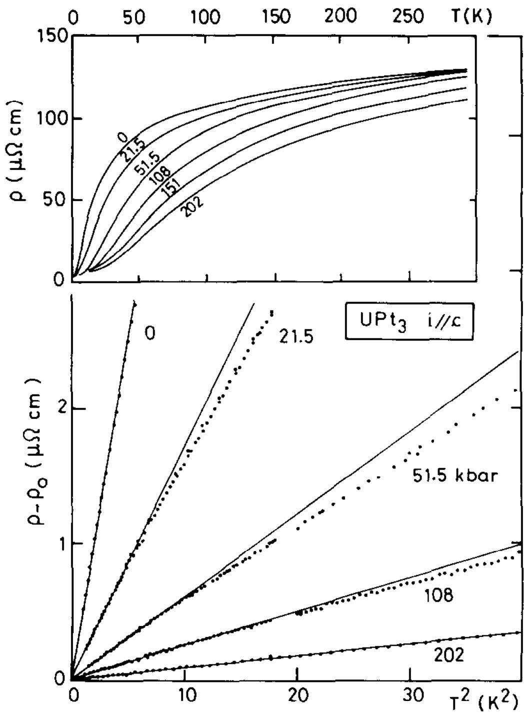

Fig. 1. High-pressure resistivity of UPt_3.

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were determined as the linear extrapolations to $T=0$ of the experimental ρ versus T^2 curves for $T>1.1$ K (see fig. 1). The residual resistivity ratios (i.e. $\rho(300\ K)/\rho_0$) are 68 in sample 1 at 21.5 kbar and 67 in sample 2 at 1 bar, appreciably larger than those reported in ref. [5] for unannealed samples, but still less than usually found in annealed ones (78 [6], 130 [2] and even 280 [3]). It is known however that in UPt_3, the physical properties in the normal state ($T>T_c \approx 0.5$ K) do not depend critically on sample quality. From our data, ρ_0 remains essentially constant below 40 kbar, in agreement with ref. [5] ($P=0$, 4.2 kbar), then increases from 1.9 to 6 $\mu\Omega$cm between 40 and 200 kbar. It is difficult to decide whether this effect is intrinsic or merely due to lattice defects produced on increasing the pressure.

The low-temperature transport properties of UPt_3 are presently believed to reflect predominantly the scattering of the conduction electrons by the spin fluctuations of the 5f electrons [1,3]. The classical theory of this mechanism leads to a T^2 term in the electrical resistivity for $T \ll T_{sf}$ [7]. From a careful analysis of the ambient-pressure data in a double logarithmic plot, it was concluded in ref. [6] that the exponent of the AT^n term approaches a value of 2 for $T<1.5$ K, with a coefficient A $\approx 0.7\ \mu\Omega$cm/K^2. The same procedure was applied here after subtracting the residual resistivities from the experimental data. The resulting values of A are displayed as the slopes of the solid lines in the ρ versus T^2 plot of fig. 1. At ambient pressure we find $A=0.52\ \mu\Omega$cm/K^2, in good agreement with the data reported in ref. [3] ($0.54\ \mu\Omega$cm/K^2). The difference with the larger value quoted above may correspond to a contribution from magnetic impurities. Under pressure, A decreases rapidly by one order of magnitude between 0 and 50 kbar, then more slowly to $8.8 \times 10^{-3}\ \mu\Omega$cm/K^2 at 202 kbar.

In the spin-fluctuation theory, one expects $A=\alpha/T_{sf}^2$ where α is a constant independent of pressure. Since there is presently a very large scatter in the estimates of $T_{sf}^0 = T_{sf}(P=0)$, $1/\sqrt{A}$ was plotted directly in fig. 2 as a function of pressure, together with the earlier data points of ref. [3] below 20 kbar. The most important result is the quasilinear increase observed in the entire pressure range. Below 40 kbar, some deviations occur, possibly due to the initial deformation of the cell on applying pressure. From the average slope, we estimate $(1/T_{sf}^0)\mathrm{d}T_{sf}/\mathrm{d}P \approx 30$ Mbar^{-1}. This value is in surprisingly good agreement with those reported previously by Wire et al [2] (30 Mbar^{-1}) and Willis et al. [3] (25 Mbar^{-1}) for the low-pressure region ($P<20$ kbar), suggesting that the same mechanism is responsible for the increase of T_{sf} ($T_{sf}(200)/T_{sf}^0 \approx 7.5$) over the entire pressure range.

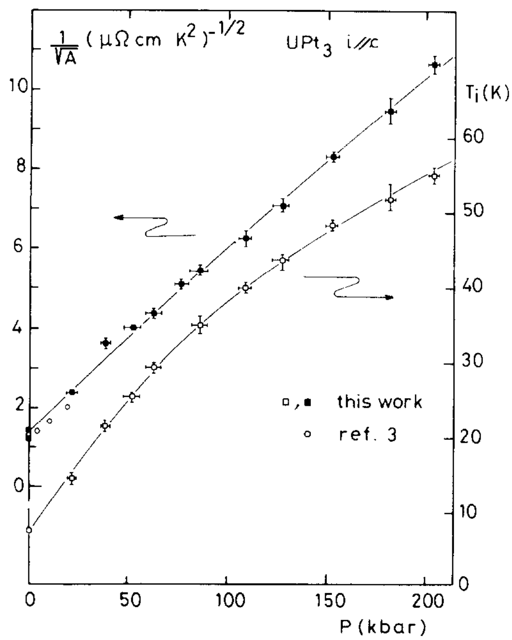

Fig. 2. Pressure dependence of $1/\sqrt{A}$ and T_i (see text) deduced from the ρ versus T curves.

According to Kaiser and Doniach's theory, ρ should be a universal function of T/T_{sf} as long as $\chi(q, \omega)$ remains constant (low-T region). In our case, the scaling is warranted by the way T_{sf} was obtained so long as the T^2 dependence holds. Deviations from a universal behavior actually appear already around the temperature T_i of the inflection point, as indicated by the non-linear relationship between T_i and $1/\sqrt{A}$ (see fig. 2). This discrepancy would be at least partly removed by proper subtraction of the phonon scattering term. Finally, it can be noted that, unlike $CeCu_2Si_2$, UPt_3 does not become superconducting at any pressure for $T>1$ K.

[1] G.R. Stewart, Z. Fisk, J.O. Willis and J.L. Smith, Phys. Rev. Lett. 52 (1984) 679.

[2] M.S. Wire, J.D. Thompson and Z. Fisk, Phys. Rev. B30 (1984) 5591.

[3] J.O. Willis, J.D. Thompson, Z. Fisk, A. de Visser, J.J.M. Franse and A. Menovsky, Phys. Rev. B31 (1985) 1654.

[4] B. Bellarbi, A. Benoit, D. Jaccard, J.M. Mignot and H.F. Braun, Phys. Rev. B30 (1984) 1182.

[5] A. Menovsky, J.J.M. Franse and A.C. Moleman, J. Crystal Growth 67 (1984) 31.

[6] A. de Visser, J.J.M. Franse and A. Menovsky, J. Magn. Magn. Mat. 43 (1984) 43.

[7] A.B. Kaiser and S. Doniach, Intern. J. Magnetism 1 (1970) 11.