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FORCED MAGNETOSTRICTION OF HEAVY-FERMION UPt_3

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The forced magnetostriction of single-crystalline UPt_3 has been measured in magnetic fields up to 8 T. For a magnetic field applied in the basal plane the forced volume magnetostriction amounts to 4.3×10^{-6} T^{-1} at 8 T and 4.3 K, whereas for a field direction along the hexagonal axis this value is at least one order of magnitude smaller. The results are related to the pressure dependence of the magnetic susceptibility.

The classification of UPt_3 as a heavy-fermion system has attracted much attention to this compound. As a result its low-temperature properties have been studied intensively. A review of these studies has recently been given by Franse et al. [1,2]. Low-temperature specific heat [3] and thermal expansion [4] data point to pronounced spin-fluctuation phenomena. The temperature dependence of the magnetic susceptibility [5] and electrical resistivity [6] can be explained within this model as well. Although a large variety of experiments has been performed up till now, the nature of the superconducting transition that was observed at 0.48 K [3,7], as well as the origin of the high-magnetic field transition near 21 T that was observed in magnetization [5] and magnetoresistivity [1,2,8] data, remain quite puzzling. Important information could be obtained from high-pressure experiments on the resistivity and susceptibility [6,9]: whereas the superconducting transition temperature decreases with pressure, the characteristic temperature governing the normal-state low-temperature properties, $T^* \approx 10$ K, increases with pressure. In order to investigate the effect of a magnetic field on the lattice parameters and in order to clarify the high-pressure data on the susceptibility we have performed magnetostriction experiments.

To this purpose a single crystalline $5 \times 5 \times 5$ mm^3 cube, the same as the one used for the thermal expansion measurements [4], was mounted in a capacitance cell, made of OFHC-copper. A sensitive three-terminal method served to determine the changes in length. A superconducting solenoid allowed applied fields up to 8 T. Care was taken to keep the sample at constant temperature ($T = 4.3$ K), since otherwise the large thermal expansion of the sample ($\alpha_{a,b} = L^{-1}(\mathrm{d}L/\mathrm{d}T) = 8.1 \times 10^{-6}$ K^{-1} and $\alpha_c = -5.3 \times 10^{-6}$ K^{-1} [4]) would obscure the forced magnetostriction, $\lambda' = L^{-1}(\mathrm{d}L/\mathrm{d}B)$. The accuracy decreases with increasing field and is limited at 1.5×10^{-7} T^{-1} in λ' at 8 T. The experimental set up allows a set of nine measurements: the field can be applied perpendicular (2 ×) and parallel to the three dilatation directions. As UPt_3 has a hexagonal structure we performed the whole set of nine measurements. Some anisotropy effects were observed in the hexagonal plane, but were in the order of the spread in the data. In this paper we neglect the basal plane anisotropy and concentrate on the overall behaviour.

The experimental results are displayed in figs. 1 and 2. For a field applied along the c-axis λ' is linear in field: positive for expansion in the basal plane, but negative along the c-axis. For a field applied along the a-axis deviations from linearity occur above 3 T. In table 1 we have listed the coefficients of the term proportional to B^2 in $\lambda = \Delta L/L$. Note that deviations from linearity are observed at considerably lower fields than in the appropriate magnetization curves (≈ 10 T) [5].

The forced magnetostriction data can be related to the hydrostatic pressure dependence of the molar magnetic moment by a thermodynamic Maxwell relation:

$$\left(\frac{\partial M}{\partial P}\right)_{H,T} = -\left(\frac{\partial V}{\partial \mu_0 H}\right)_{P,T}, \qquad (1)$$

or in terms of the relative pressure dependence of the

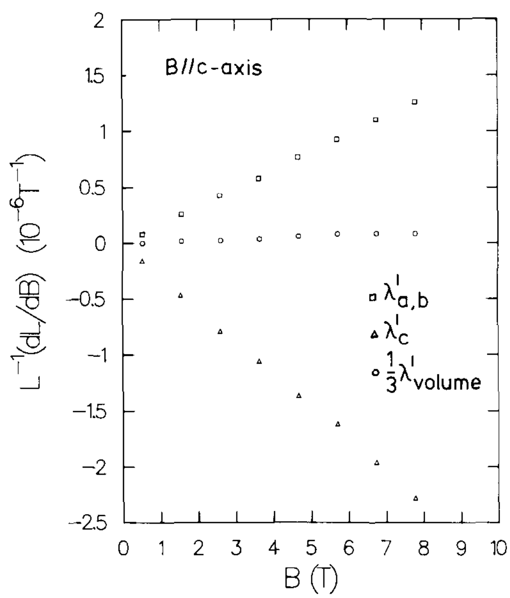

Fig. 1. The forced magnetostriction of single-crystalline UPt_3 for a field applied along the c-axis at $T = 4.3$ K: in the basal plane, $\lambda'_{a,b}$; along the hexagonal axis, λ'_c; and the volume effect λ'_{volume} (here shown $\frac{1}{3}\lambda'_{volume}$).

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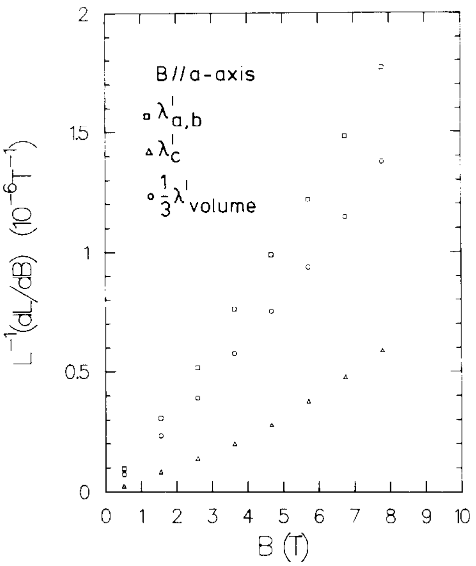

Fig. 2. The forced magnetostriction of single-crystalline UPt_3 for a field applied along the a-axis at $T = 4.3$ K: in the basal plane, $\lambda'_{a,b}$; along the hexagonal axis, λ'_c; and the volume effect λ'_{volume} (here shown $\frac{1}{3}\lambda'_{volume}$).

molar magnetic susceptibility

$$\frac{H\chi}{V}\left(\frac{\partial \ln \chi}{\partial P}\right)_{H,T} = -\frac{1}{V}\left(\frac{\partial V}{\partial \mu_0 H}\right)_{P,T}. \qquad (2)$$

Here $V(= 4.24 \times 10^{-5}$ $m^3/mol)$ is the molar volume. With the appropriate susceptibility data, $\chi_{a,b} = 107 \times 10^{-9}$ m^3/mol and $\chi_c = 57 \times 10^{-9}$ m^3/mol [5], we calculate from the data in table 1, values for $\partial \ln\chi/\partial P$ of -23 and -3 $Mbar^{-1}$, for a field direction in the basal plane or along the hexagonal axis, respectively. Thus, applying a field in the basal plane would result in a relative pressure dependence (-23 $Mbar^{-1}$) which is nearly one order of magnitude larger than for a field direction along the hexagonal axis. The calculated $\partial \ln \chi/\partial P$-value for a field direction in the basal plane

Table 1
Coefficient a (in 10^{-7} T^{-2}) of the B^2-term for field directions along the a, b and c-axis, as derived from the forced magnetostriction data: $\lambda = \Delta L/L = aB^2 + \cdots$. Note that for field directions in the basal plane deviations from the B^2-dependence occur above 3 T

	Field along		
	a-axis	b-axis	c-axis
Dilatation in basal plane	2.00	2.02	1.61
Dilatation along hexagonal axis	0.57	0.62	−2.91
Volume effect	4.57	4.66	0.31

agrees nicely with the experimental value obtained in a high-pressure experiment on a polycrystalline sample with a considerable amount of preferred orientation: $\partial \ln \chi/\partial P = -24$ $Mbar^{-1}$, with $\chi(4.2\ K) = 104 \times 10^{-9}$ m^3/mol [9].

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