Length change experiments on UPt₃ in high magnetic fields

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Abstract

We present thermal-expansion and forced-magnetostriction experiments on UPt₃ in the temperature range 1.5–17 K and in magnetic fields parallel to the crystallographic a-axis up to 25 T, well above the metamagnetic field, B^*, of 20 T. For this field direction the length changes along the a-, b- and c-axis have been determined. We observe that the Grüneisen parameter, reflecting the relative strain dependence of the effective mass, collapses abruptly above B^*. In addition, we observe a feature for $B > B^*$ that is reminiscent of a re-entrance of the heavy-fermion state.

UPt₃ can be considered as a prototype system for the U-based heavy-fermion (HF) systems. Since hybridization plays an important role in the HF systems, huge effects in the magnetostriction (MS) and thermal expansion (TE) can be expected and have been observed indeed in a number of systems [1]. From a combination of thermal-expansion and specific-heat data, not only values for a volume Grüneisen parameter can be deduced but also the relative strain dependence of the effective mass along each crystallographic direction separately. These parameters show interesting features around and above the metamagnetic field, B^*, as we shall demonstrate in this contribution. From the MS and TE experiments, the length changes as a function of applied field along the a-axis and temperature have been determined. The results will be presented in a three-dimensional $\Delta L/L$ versus B, T diagram.

The experiments have been performed on the same sample as used in previous specific-heat [2] and MS [3] measurements. Length changes were measured using a parallel-plate capacitance method. The forced MS data

nicely complete the previously reported results of Ref. [3] and reveal a sharp peak at B^* which rapidly decreases in amplitude with increasing temperatures. Measured along the c-axis, the peak in the magnetostriction is about four times smaller than along the a- and b-axis. The thermal expansion ($L^{-1} \Delta L/\Delta T$) data at different field values are shown in Fig. 1. The curves for the a- and b-direction reveal for fields below B^* a steep increase with increasing temperatures to some maximal value. The temperature at which the maximum occurs is supposed to be related to the characteristic temperature T^* for the heavy-fermion behaviour and is found to shift to lower temperatures for increasing field values not exceeding B^*. At fields above B^*, the thermal expansion curves do not reveal this maximum and monotonously increase with temperature in the studied temperature range. However, still a large field effect is observed in this region. One should realize that phonons are hardly field dependent, so this effect must stem from the electronic part of the system. Along the c-direction a monotonous decrease with increasing temperature is observed with hardly any effect of an applied magnetic field. We note that the curve obtained at a field of 24.5 T along the b-direction starts at the
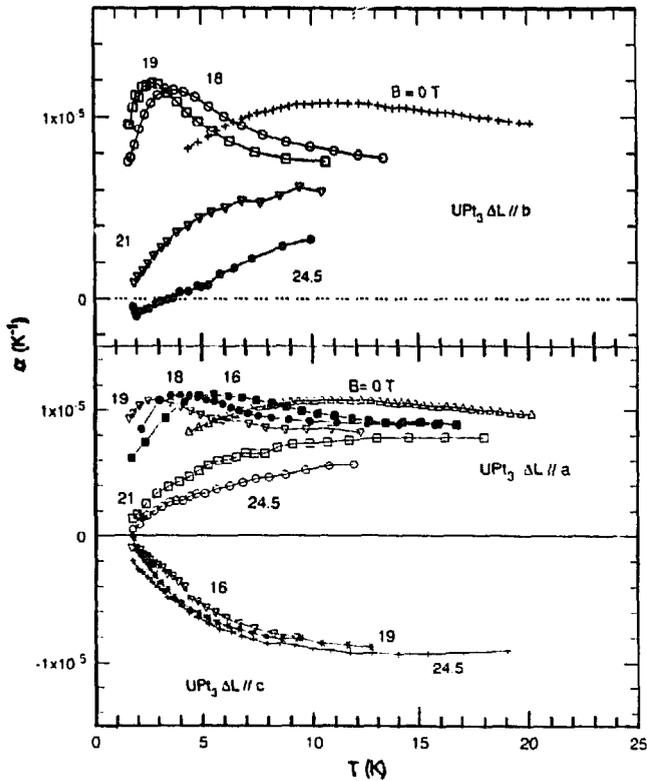
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Fig. 1. Thermal expansion data $(B\|a)$ in fields above and below $B^* = 20$ T along the crystallographic b-, a- and c-direction (from top to bottom).
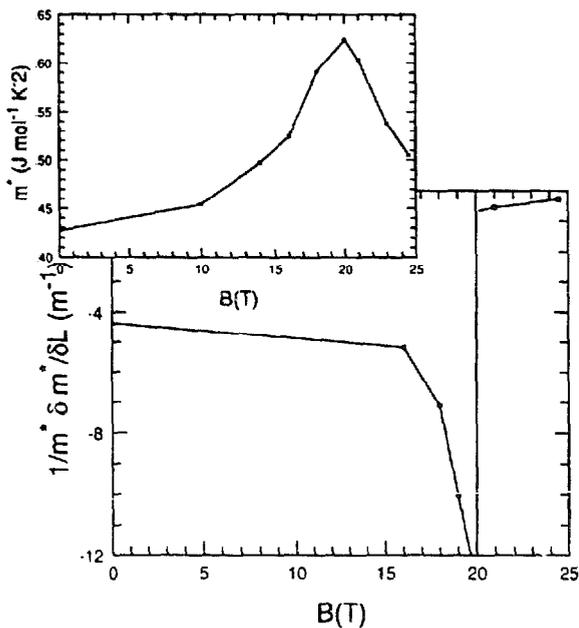

Fig. 2. Plot of the parameter τ_a ($- \partial \ln m^* / \partial x_a$), with x_a being the relative length change along the a-axis, as a function of field. The inset shows the field dependence of the coefficient of the linear term of the temperature dependence of the specific heat (taken from Ref. [2]) which is proportional to m^*.

lowest temperatures with negative values in contrast to the curve along the a-direction. This anisotropy could possibly be related to the preference of the uranium moments to be oriented along the b-direction.

In order to analyse further the thermal-expansion results, we compare the thermal expansion and the specific heat in the studied field and temperature intervals. The specific-heat measurements in field by Van der Meulen et al. [2] show a broad maximum for the coefficient γ of the linear term in temperature of the specific heat, reflecting the field dependence of the effective electronic mass, m^*. Following the same Fermi-liquid-like argument as for m^* and for the specific heat, it can be shown that the linear term in temperature of the thermal expansion, a_0^i, along a specific crystallographic direction (indicated by the superscipt) or a_0^i/γ to be even more precise, is proportional to the relative strain dependence of the effective mass which dependence will be expressed in terms of the parameter τ: $\tau_i = \partial \ln m^*/\partial x_i$ with x_i representing the relative length change along this specific crystallographic direction. The parameters τ_a and τ_b as derived from a combination of thermal-expansion and specific-heat data, show a quite irregular behaviour as a function of the applied field, especially in the neighbourhood of the metamagnetic field B^*, see Fig. 2. This could indicate the presence of an anomalous structure in the density of states (DOS), such as e.g. the states in the uppermost part in the peak of the DOS having a different strain dependence than the remaining states.

Combining the thermal-expansion data in field along the three main crystallographic directions, the temperature dependence of the volume Grüneisen parameter, to be identified as the negative volume derivative of m^*, can
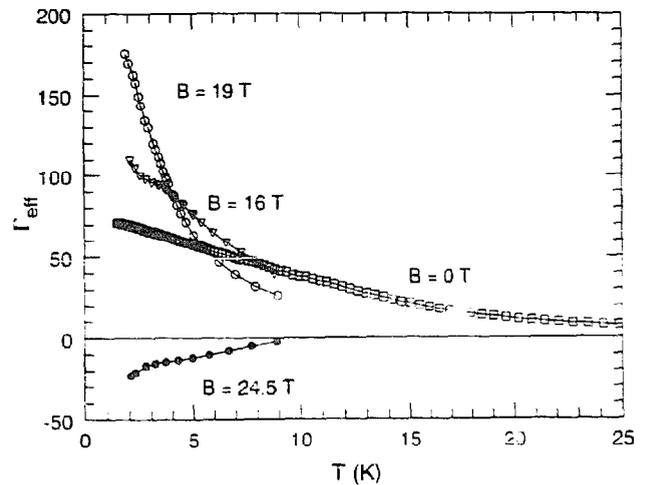

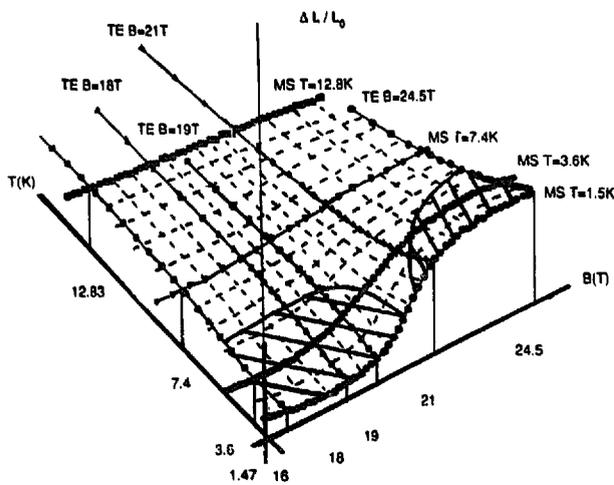Fig. 3. Volume Grüneisen parameter for fields above and below $B^* = 20$ T as a function of temperature $(B\|a)$.

Fig. 4. Relative length change of the *a*-axis versus *B* in the interval $16\,T < B < 24.5\,T$ and versus *T* in the interval $1.5\,K < T < 12.8\,K$ as deduced from magnetostriction (MS) and thermal-expansion (TE) data. The type of experiment, the temperature and the field at which the experiments have been performed are indicated in the figure. Dashed areas indicate the regions with heavy-fermion-like features.

be deduced. This parameter again shows a drastic collapse at B^* over the temperature range studied, see Fig. 3.

A plot of $\Delta L/L$ along the *a*-axis as a function of temperature and field applied along the *a*-axis is presented in Fig. 4. The heavy-fermion state is observable in this diagram as a pronounced "valley" in the $\Delta L/L$ data. A second valley seems to be present in the data for $B > B^*$ and $T < 5\,K$, suggesting a re-entrance of the heavy-fermion state.

In conclusion, from analysing our data we found a sharp collapse of the parameter τ and of the Grüneisen parameter at B^*, while the effective mass exhibits a broad maximum at this field. A diagram of the length along the *a*-axis as a function of field parallel to the *a*-axis and of temperature has been constructed. A feature with the same characteristics as that of the heavy-fermion state appears in this diagram for $B > B^*$ at low temperatures.

References

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