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OBSERVATION OF MAGNETIC ORDER IN THE HEAVY FERMION SUPERCONDUCTOR  $UBe_{13}$

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We have measured the magnetostriction,  $L(H)$ , of a single crystal of the Heavy Fermion superconductor,  $UBe_{13}$ , using an all silicon high precision capacitance dilatometer. We find clear evidence for a transition to an antiferromagnetic state at  $T_N \sim 8.8K$ , which is suppressed in a field by  $dT_N/dH \sim 0.36K/T$ . At low temperatures we observe pronounced magnetostrictive oscillations, which we believe are de Haas-van Alphen oscillations due to an unusual aspect of the Fermi surface.

1. INTRODUCTION

Recent work has shown the strong relationship between magnetism and superconductivity in the heavy fermion superconductors. In  $UPt_3$ , with  $T_c \sim 0.55K$ , an antiferromagnetic transition is observed (1) with  $T_N \sim 5.0K$ . In  $URu_2Si_2$ , with  $T_c \sim 1.2K$ , there is a transition (2) to an antiferromagnetic state at  $T_N \sim 17.5K$ . In  $UBe_{13}$ , with  $T_c \sim 0.8K$  a magnetic transition above  $T_c$  has not been reported previously (3). We find clear evidence for an antiferromagnetic transition at  $T_N \sim 8.8K$ . This strongly suggests that the presence of a magnetic transition with  $T_N \sim 10 T_c$  is a general feature of superconductivity in this class of materials. At low temperatures we see unusual magnetostrictive oscillations, not previously observed in any system, which we believe are related to the de Haas-van Alphen effect and to the magnetism we observe.

2. TECHNIQUE AND MATERIALS

Dilatometry measurements are valuable for the study of weakly magnetic systems due to their high sensitivity. This technique is especially justified for the heavy fermion systems, since they not only have strongly enhanced electronic properties due to the mass renormalization, but also have strongly enhanced Gruneisen parameters (4), typically  $\gamma_e \equiv \frac{d\ell n\gamma}{d\ell nV} \sim 100$ , where  $\gamma$  is the linear specific heat coefficient. Assuming that  $\vec{M}$  points along  $\vec{H}$ ,  $m = \chi H$ , and that the dilatations are isotropic, it follows that (5)  $\frac{1}{L} \frac{dL}{dH} = \frac{1}{3} \kappa \gamma_m m$  where  $m = MV$  is the magnetization/unit volume,  $\kappa$  is the compressibility, and  $\gamma_m$  the magnetic Gruneisen parameter  $\gamma_m \equiv \frac{d\ell n\chi}{d\ell nV}$ .

The dilatometer itself is constructed *only* from single crystal silicon to achieve high stability for magnetostrictive measurements, and is ideal for thermal expansion measurements as well, since its length changes at low temperatures are negligible. With this cell design we achieved a sensitivity of  $\Delta L/L \sim 3 \times 10^{-9}$  for measurements either as a function of  $H$  or  $T$ .

The sample was grown from an Al melt using standard Czochralski techniques having dimensions  $\sim 5 \times 5 \times 5 \text{ mm}^3$ . The magnetic field was applied along a [100] direction and the dilatation measured along a perpendicular [100] direction. The capacitance ( $C_0 \sim 5 \text{ pF}$ ) was measured using a 3-terminal capacitance bridge.

The thermal expansion of  $UBe_{13}$  has been measured by Ott, (6) et al. at  $H = 0$  for  $0.3 < T < 10K$ . Our study of the thermal expansion in the superconducting state and up to  $20K$  is the subject of a later work, (7) but is generally consistent with their results.

3. RESULTS

In order to directly measure the quantity of interest,  $dL/dH$ , we added a very low frequency ( $\sim 10^{-3} \text{ Hz}$ ) field modulation of  $\sim 1 \text{ kG}$  to the applied field, while recording the consequent modulations of the length of the sample. The amplitude was measured at a number of temperatures, tracing out a curve equivalent to  $M(T)$  as shown in Fig. 1 for  $H_0 = 3T$  and  $H_0 = 7T$ . The curves have the characteristic shape of an order parameter, being constant at low temperatures and vanishing at  $7.65$  and  $6.33K$  respectively. We believe that the shape of the  $dL/dH$  curves is clear evidence for magnetic ordering and the suppression of the transition temperature ( $dT_N/dH \sim 0.36T/K$ ) in a field indicates that it is antiferromagnetic in nature. The transition temperatures extrapolate to  $T_N = 8.8 \pm 0.2K$  for  $H=0$ .

We have measured  $dL/dH$  vs.  $T$  for a number of fields between  $5$  and  $78.5 \text{ kG}$ . The low temperature values of  $1/L(dL/dH)$  are plotted vs.  $H$  in the inset to Fig. 1 showing a linear variation with field. From the slope of this line, and using  $\kappa = 8 \times 10^{-13} \text{ cm}^3/\text{erg}$ , we find that  $\gamma_m \chi \sim 2.9 \times 10^{-3} \text{ emu/cm}^3$ , which is approximately 16 times higher than the measured low temperature value for the Pauli susceptibility,  $\chi_0$ .

While no hysteresis is observed in the curves of  $dL/dH$  as a function of temperature, there is significant hysteresis as a function of magnetic field for  $T < T_N$ . In Fig. 2 we show plots of  $L(H)$ , taken at constant temperature, and sweep rates  $dH/dt \sim 0.3 \text{ mT/s}$ . Fig. 2(a) is for  $T > T_N$ , ( $T=10.0K$ ) and shows no magnetic hysteresis. Fig. 2(b) is for  $T < T_N$  ( $T=4.0K$ ) and shows significant magnetic hysteresis. Fig. 2(c) is for  $T = 1.25K$  and shows sharp jumps in  $L(H)$  at specific fields, which fall within an envelope like that of Fig. 2(b). Upon repetition such a trace appears similar, but the jumps do not occur at precisely the same field. Fig. 2(d) is for  $T = 0.825K$ , and shows that the frequency of the jumps has increased. They are now reduced in amplitude, but appear more convincingly to be oscillatory, perhaps periodic in  $1/H$ . With Fig. 2(e) at  $T = 0.600K$  this trend continues. The anomaly below  $2.6T$  is associated with  $H_{c2}$  ( $0.600K$ ) and is discussed elsewhere. (7)

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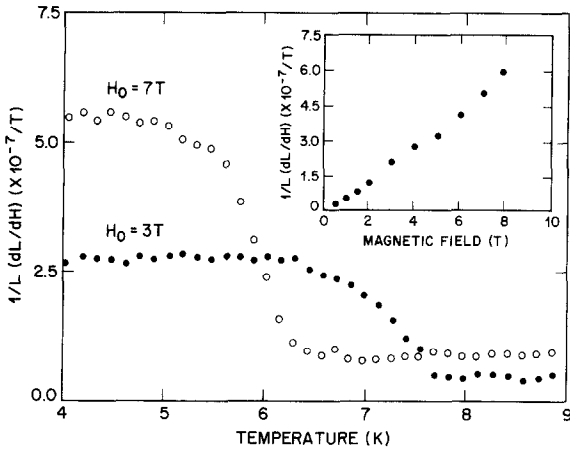


FIGURE 1

#### 4. DISCUSSION

The oscillatory magnetostriction shown in Fig. 2 is reminiscent of the de Haas-van Alphen effect. However, our observations are not consistent with conventional expectations for it. The oscillation frequency is given by  $\omega_{1/B} = \phi_0 S$  where  $\phi_0 = hc/e$ , and  $S$  is an extremal area of the Fermi surface. The Fermi surface topology determines  $S$  and rarely deviates by more than  $10^{-4}$ . In our measurements  $\omega_{1/B}$  changes drastically, with  $\omega_{1/B} \propto 1/T^3$  for  $0.6 < T < 1.25$  K. The oscillation amplitude is predicted to have a  $T$  and  $H$  dependence which we do not observe. Finally, de Haas-van Alphen oscillations are sinusoidal and non-hysteretic, whereas here the oscillations appear as first order jumps.

We believe that modifications appropriate to  $UBe_{13}$  can help to explain our results. The amplitude of the magnetostrictive oscillations can be directly related (6) to the magnetization oscillations by replacing  $\gamma_m$  with  $\gamma_S$ , where  $\gamma_S = \frac{d^n S}{d^n V}$  is a Grüneisen parameter associated with the extremal orbit area  $S$ . This can result in a tremendous enhancement over the usual oscillation amplitude. The first order nature of the jumps can be understood in terms of magnetic interaction (8). The oscillations are governed not by the applied field,  $H$ , but by the internal field  $B = H + 4\pi M$ . If  $M$  becomes comparable to the oscillation period the system is in a metastable state during part of the cycle and undergoes a transition to a lower energy state only after a suitable nucleation process. The strong temperature dependence to the oscillation frequency may be due to the formation and opening up of a neck between parts of the Fermi surface. In this temperature range the effective mass renormalization is rapidly increasing, which may be reflected in the Fermi surface topology. Finally, the change in oscillation rate may only be an apparent one, due to a change in nucleation rate with temperature.

#### 5. CONCLUSION

We have found that  $UBe_{13}$  orders into an antiferromagnetic state with  $T_N \sim 8.8$  K, which is suppressed in a field with  $dT_N/dH \sim 0.36$  K/T. Below  $\sim 3$  K we observe very unusual magnetostrictive oscillations, which we believe can be understood in the context of the de Haas-van Alphen effect.

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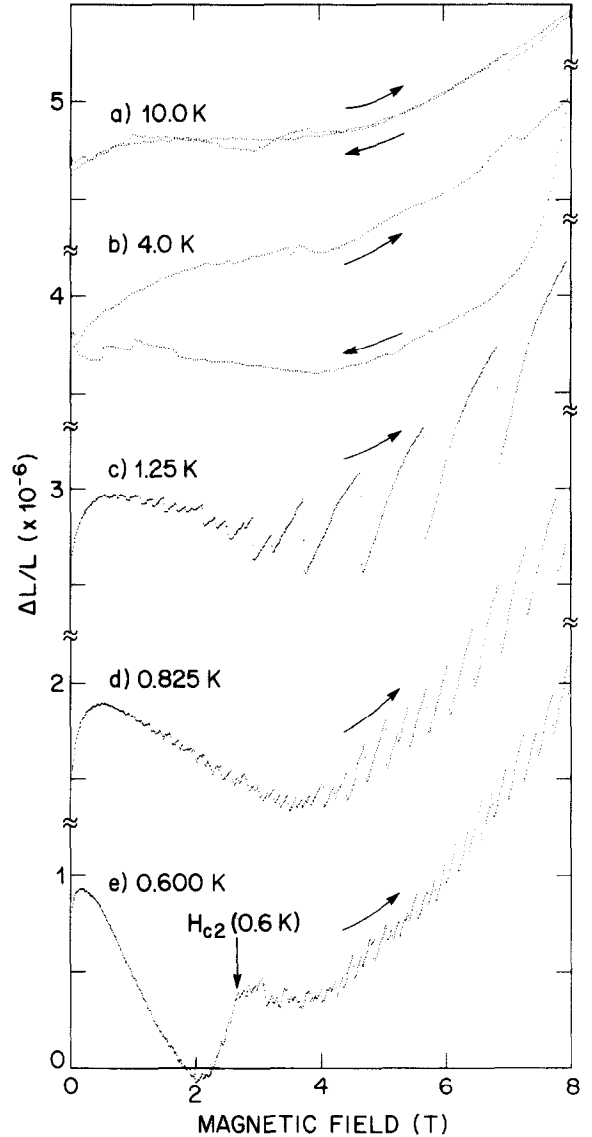


FIGURE 2

#### REFERENCES

- (1) G. Aeppli, et al. Phys. Rev. Lett. 60, 615 (1988).
- (2) T. T. M. Palstra, et al. Phys. Rev. Lett. 55, 2727 (1985); C. Broholm, et al. Phys. Rev. Lett. 58, 1467 (1987).
- (3) It has been suggested however that pure  $UBe_{13}$  becomes magnetically ordered for  $T < T_c$  as in  $U_{1-x}Th_xBe_{13}$ .
- (4) B. S. Chandrasekhar and E. Fawcett, Adv. Phys. 20, 775 (1971).
- (5) A. de Visser, et al. Physica 147 B, 81 (1987).
- (6) H. R. Ott, Physica B 126, 100 (1984).
- (7) R. N. Kleiman, et al. (1989) to be published.
- (8) A. B. Pippard, Proc. Roy. Soc. A 272, 192 (1963); Electrons at the Fermi Surface, ed. M. Springford (Cambridge University Press, Cambridge, 1980) Chap. 4.