A HEAT CAPACITY ANOMALY AT T^* IN A FERROMAGNETIC SUPERCONDUCTOR UGe_2*

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We performed the heat capacity, $C(T)$, measurement under high pressure for a ferromagnetic superconductor UGe_2. At 1.15 GPa, we found a peak in C/T at a characteristic temperature, $T^* = 6$ K where the magnetization showed anomalous increase. At 1.28 GPa, above the critical pressure P_{C}^* where T^* becomes 0 K, C/T does not show notable anomaly at zero magnetic field, but the application of the external field above 2.5 T induces the peak again at $T^* > 0$ K. It corresponds to the induction of T^* by the magnetic field. Our experimental result suggests that a second order phase transition takes place at T^* and thus a disappearance of the phase transition at T^* is of second order.

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1. Introduction

UGe_2 is a material in which superconductivity and ferromagnetism coexists [1, 2]. Superconductivity was observed in the pressure range from 1.0 to 1.6 GPa where UGe_2 is still in the ferromagnetic state. This is a first case where a ferromagnet becomes a superconductor.

It is known that an another anomaly exists in the resistivity, the magnetization and the thermal expansion measurements at a characteristic temperature T^* in the ferromagnetically ordered state [1–5]. The superconducting temperature T^*_{SC} shows maximum around the critical pressure P^*_C where T^* becomes 0 K. Thus it is supposed that the superconductivity is mediated by the critical magnetic fluctuation around P^*_C.Watanabe and Miyake developed a microscopic theory for the superconductivity, assuming that T^* is a coupled CDW/SDW transition temperature [6]. However the microscopic origin of T^* is not clear experimentally at present. Moreover, it is not clear that a thermodynamic phase transition occurs at T^*. In this paper, we report the observation of a peak in the heat capacity at T^*, which strongly suggests that a phase transition takes place at T^*.

2. Experimental

A single crystal was grown by the Czochralski pulling method in a tetra-arc furnace as described in Ref. [3]. The residual resistivity ratio (RRR) was 600 at ambient pressure for the present sample, which indicated a good quality of our sample. The heat capacity, $C(T)$, was measured by the adiabatic heat pulse method. The magnetization, $M(T)$, measurement was carried out using a SQUID magnetometer. Pressure was applied by utilizing a Cu–Be piston cylinder type cell with a Daphne oil (7373) as a pressure-transmitting medium. In the present experiments, the heat capacity and magnetization experiments were carried out simultaneously in order to obtain the data in a same pressure condition.

3. Result and discussion

Figure 1 shows the temperature dependence of C/T for 1.15 and 1.28 GPa, plotted with the magnetization under the magnetic field of 0.5 T. At 1.15 GPa, the magnetization shows an anomalous increase around $T^* \sim 6$ K as we reported previously [5]. Correspondingly a heat capacity anomaly appears in the heat capacity at T^*, which suggests that a thermodynamic phase transition occurs at T^*. We define the transition temperature T^* as 6.1 K such that the entropy is conserved as drawn by a broken line in Fig. 1. At 1.28 GPa, above P^*_C, there is no anomaly in both the heat capacity and magnetization.

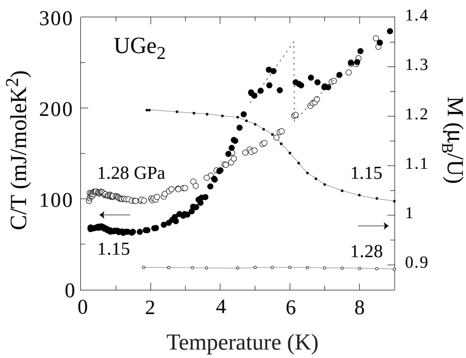

Fig. 1. Temperature dependence of C/T and the magnetization for 1.15 and 1.28 GPa in UGe_2.

The linear coefficient of the heat capacity γ , which is determined by the extrapolation of C/T to 0 K, is about 70, 100 mJ/moleK^2 at 1.15 and 1.28 GPa, respectively. These values are quantitatively consistent with the pressure dependence of γ in our previous study [3].

To obtain the absolute value of the entropy, we extrapolate the C/T curve to zero temperature. Then the total entropy is obtained by integrating the C/T curve with respect to T, as shown in figure 2. It is characteristics that the T-dependence of the entropy above T^* in 1.15 GPa follows that of1.28 GPa where the heat capacity anomaly is absent. This suggests that the phase transition at T^* is of a second order type and the large γ value above P_C^* is originated from a critical fluctuation around the second order critical point P_C^*. The entropy balance below and above P_C^* is not expected in the case of first order transition. At 1.28 GPa, the application of the external field

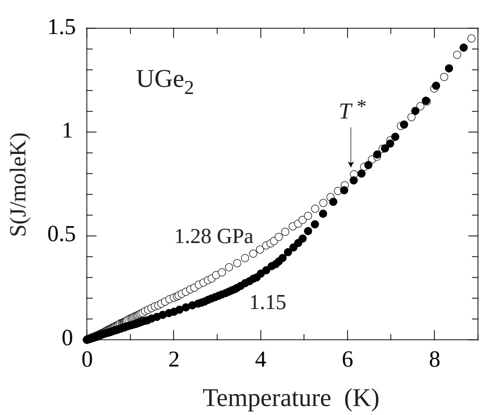

Fig. 2. Temperature dependence of the entropy in 1.15 and 1.28 GPa in UGe_2.

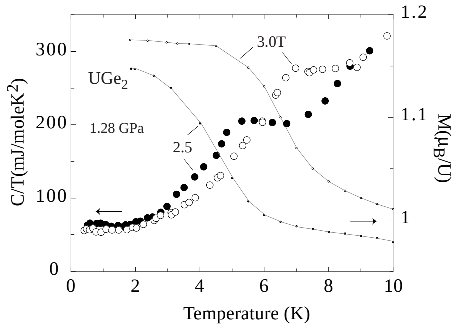

Fig. 3. Temperature dependence of C/T and magnetization for 1.28 GPa under several magnetic fields in UGe_2.

parallel to the spin easy axis induces the heat capacity anomaly as shown in figure 3. This agrees with the magnetization and resistivity anomaly reported previously [2, 5, 7].

4. Summary

In conclusion, we observe a peak in the heat capacity at T^*. It is strongly suggested that a second order thermodynamic phase transition occurs at T^*.

REFERENCES

[1] S.S. Saxena *et al., Nature* **406**, 587 (2000).
[2] A. Huxley *et al., Phys. Rev.* **B63**, 144519 (2001).
[3] N. Tateiwa *et al., J. Phys.: Condense. Matter* **13**, L17 (2001).
[4] N. Tateiwa *et al., J. Phys. Soc. Jpn.* **70**, 2876 (2001).
[5] G. Oomi *et al., Physica B* **186-188**, 758 (1993).
[6] S.Watanabe, K. Miyake: to be published in *J. Phys. Soc. Jpn.*
[7] T. C. Kobayashi *et al.*, `cond-mat/0107584`.