Physica B 165&166 (1990) 369-370
North-Holland

ULTRASONIC STUDY OF THE SUPERCONDUCTING PHASES IN HEAVY FERMION COMPOUNDS

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We studied elastic constants, ultrasonic attenuation and ac-susceptibility in the superconducting states of the heavy fermion compounds UPt_3 and URu_2Si_2. Both materials show steps in some, but not all elastic constants at the superconducting transitions. For UPt_3 we present a B-T phase diagram for fields along a,b and c axis and compare it with existing theories.

1. UPt_3

The heavy fermion compound UPt_3 is already extensively investigated by ultrasonic experiments [1-4]. On a high quality single crystal we performed measurements of the elastic constants (c_{11}, c_{33}, c_{44}), the corresponding ultrasonic attenuation and the magnetic ac-susceptibility χ as function of temperature as well as magnetic field strength for various field directions. With these experiments we obtained a detailed phase diagram exhibiting a double superconducting transition. As a function of temperature, this splitting was seen in the specific heat data [5].

1.2 EXPERIMENTS

In the elastic constants $c_{11}$and c_{33} step like anomalies of the order of 10^{-5} were observed. Measurements as a function of temperature at constant magnetic field show a step going down at T_c^x and a kink at T_c^y. Versus magnetic field we observe two clear steps (see fig.1). The ultrasonic attenuation does not show much structure. It will be discussed elsewhere [6]. In the ac susceptibility we also observed the splitting in the phase transtition. This is surprising, since at a measuring frequency of 128 Hz one expects primarily shielding effects. Fig. 2 gives the phase diagram for B//a,b and B//c exhibiting three superconducting phases [6].

1.3 THEORETICAL CONSIDERATIONS

On the basis of group theoretical considerations together with a coupling of a spin density wave to the superconducting pairing function a splitting of T_c and a phase diagram similar to the observed one can be deduced [7].

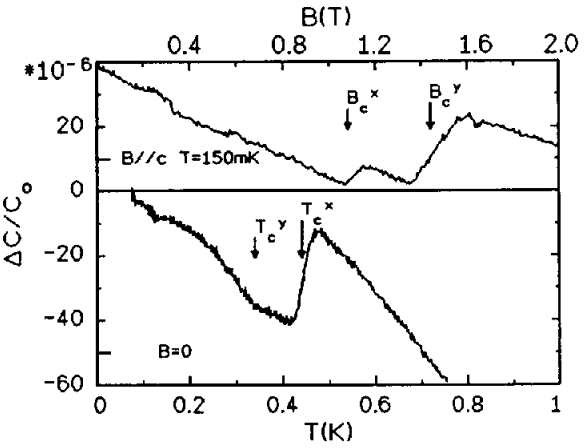

Fig.1. c_{11} mode in UPt_3 vs. B at T=150mK and vs. T at B=0T.

Theoretically, a coupling of the symmetrized strains to the square of the two component superconducting order parameter (η_x,η_y) lead for c_{11} and c_{33} to two steps of equal size as a function of temperature as well as of magnetic field. Experimentally, we do observe two steps as a function of field very clearly, whereas as a function of temperature we see one step and a kink (see Fig.1). The phase diagram in fig.2 is constructed from the T_c^{1}'s and B_c^{1}'s like the ones marked in Fig.1. It consists of phases ($\eta_x \neq 0$) bordered by the full lines and a phase ($\eta_y \neq 0$) marked by the dotted line. The ($\eta_y \neq 0$) phase is very similar for all three directions of the field, the ($\eta_x \neq 0$) phase is identical for B//a and B//b, but different for B//c. The phase at very low fields is probably due to B_{c1} [3]. A detailed analysis is following [6].

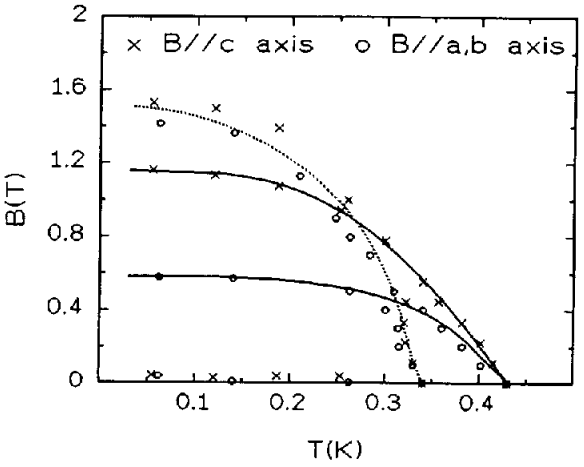

Fig.2. Superconducting phases in UPt_3. Full lines: η_x phases. Dotted line: η_y phase, see text.

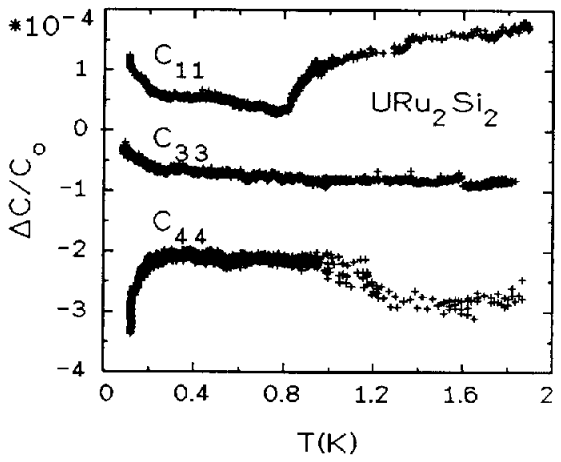

Fig.3. c_{11},c_{33} and c_{44} modes in URu_2Si_2 vs. T at B=0T (10-50MHz).

2. URu_2Si_2

URu_2Si_2 exhibits an antiferromagnetic and a superconducting transition at T_N=17.5K and T_c=1.2K, respectively [8]. To characterize our single crystal we determined the transition temperature T_c and the critical field B_{c2} via ac-susceptibility with B in the a,b-plane. The same ultrasonic measurements as in UPt_3 were performed in URu_2Si_2.

2.1 EXPERIMENTS

From our measurements we obtained T_c=1.13K and an initial slope of the B_{c2} - curve of 8.85 (T/K). Generally URu_2Si_2 exhibits a broader superconducting transition than UPt_3. For our crystal the width is nearly 200mK and similar to [9]. Fig.3 shows the temperature dependence of the elastic constants c_{11}, c_{33} and c_{44} in zero magnetic field. The superconducting transition is only visible in the c_{11} - mode and leads to a change of $5x10^{-5}$ after subtracting the background of the antiferromagnetic phase (as determined from a measurement in a 5 Tesla field). Below 0.25K all elastic constants show anomalies. In the longitudinal modes c_{11} and c_{33} an increase and in the transverse mode c_{44} a pronounced softening is observed. The softening seems to be independent of magnetic fields up to 2.5T. When measuring the magnetic field dependence at a fixed temperature we observed anomalies in all elastic constants at B_{c2}. We do not have yet the interpretation for these anomalies for T<0.25 K.

Part of this work was supported by SFB 252.

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