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Ultrasound studies of U_2Zn_{17} and UCu_5

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Abstract

We present here resonant ultrasound spectroscopy measurements of the elastic moduli and attenuation for U_2Zn_{17} and UCu_5 through the respective T_N's of 9.7 and 15 K. For single-crystal U_2Zn_{17}, the data are the first modulus measurements for this material, and exhibit a very large softening of the sound velocity and an anomalous increase in attenuation below T_N, while no precursors at all are observed above. Polycrystalline UCu_5, in contrast, exhibits weak softening above T_N, and a weak stiffening below.

The heavy electron compounds U_2Zn_{17} and UCu_5 both develop commensurate antiferromagnetic (AFM) order. UCu_5 displays a minimum in the resistivity between 0.5 and 1.5 K indicating another phase transition, but of unknown origin [1], while the resistivity of U_2Zn_{17} decreases monotonically below the AFM transition. These compounds also exhibit clear anomalies in the μSR relaxation rates [2]. For UCu_5, an expected and characteristic λ anomaly occurs at T_N, with an onset of about $4T_N$. In contrast, U_2Zn_{17} exhibits no temperature dependence in the μSR relaxation rate above T_N, while below, the rate increases continuously, eventually saturating, indicating that fluctuations do not play a role.

In contrast, the specific heat anomalies associated with AFM order in both materials are very typical looking second-order types [3], with the addition of some spin-wave contributions in U_2Zn_{17}. Measurement of the sound velocity and attenuation, then, should be important to complete the thermodynamic picture. Accordingly, we grew single crystals of U_2Zn_{17} from a stoichiometric melt. We also prepared annealed polycrystals of $UCu_{5.05}$ by arc melting and then annealing at 1023 K for four days. Metallographic examination of the $UCu_{5.05}$ sample showed that fine lamellae of a presumably Cu-rich phase were present. The excess copper was used to stabilize the material for the later production of single crystals using a zone-melting technique. To ensure that this excess Cu did not affect the ultrasound measurements, a small flake of stoichiometric UCu_5 was also measured, with nearly identical results. Both samples were cut into small rectangular parallelipipeds in preparation for resonant ultrasound spectroscopy (RUS) [4] measurements at room temperature, and a small flake of U_2Zn_{17} was used cold. From these measurements, we obtained the first determination of the moduli of U_2Zn_{17}, shown in Table 1 in an hexagonal basis set (a natural choice for a rhombohedral crystal structure). Unfortunately, however, the weak phase separation in the UCu_5 polycrystal made it impossible to obtain accurate moduli for it. The magnetic susceptibility for the two samples is

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Table 1
Elastic moduli of a single crystal of U_2Zn_{17} at 295 K in 10^{12} dyn/cm^2 using an hexagonal basis. The sample had a measured density of 8.424 gm/cm^3 with dimensions of 0.1395, 0.1797 and 0.2111 cm

c_{33}	c_{23}	c_{12}	c_{44}	c_{66}
1.668 ± 1%	0.410 ± 1%	0.474 ± 0.05%	0.552 ± 0.2%	0.565 ± 0.06%

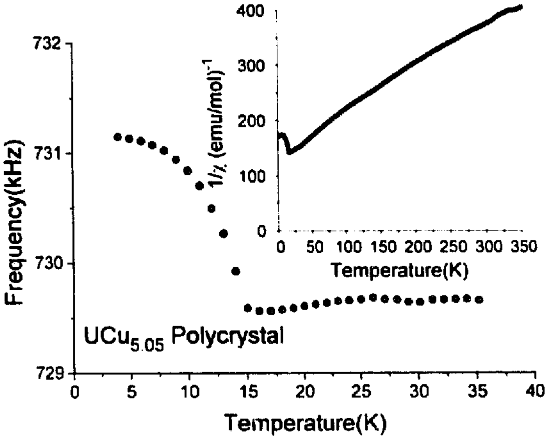

Fig. 1. Shown is a resonant frequency of the UCu_5 polycrystal that depends on both the shear and compressional moduli versus temperature. The inverse magnetic susceptibility is plotted in the inset. Note that the curvature makes a good Curie–Weiss fit difficult.

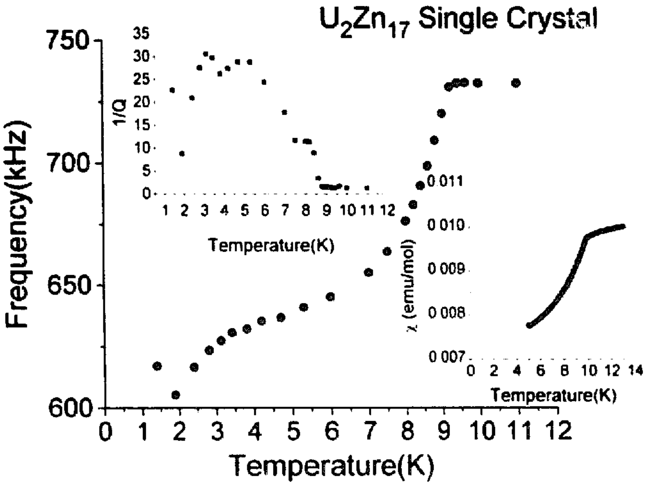

Fig. 2. A resonance dependent on compressional moduli of a U_2Zn_{17} single crystal flake is plotted. The insets are the low-temperature magnetic susceptibility showing the sharp onset of the AFM state, and 1/Q proportional to the ultrasonic attenuation.

shown in the insets of Figs. 1 and 2. Neither sample is simple Curie–Weiss, but both exhibit the expected behavior near the AFM transition.

The expected temperature dependence in the moduli at an AFM transition can be crudely predicted by a mean-field argument. If the order parameter is the sublattice magnetization, then one expects that the order parameter must couple quadratically to the strains. This is because in zero field it is difficult to envision how the sign of the sublattice magnetization could be important to the free energy. Quadratic (or higher) coupling would induce a step discontinuity in mean field, to which one adds fluctuations that would round the step on either side with the same critical exponent, and with an increase in ultrasonic attenuation in the fluctuation regime. What is observed in the resonances (moduli are proportional to the square of the resonance frequencies) and inverse Q (1/Q is a measure of the attenuation) for both materials is quite different. In Fig. 1 is shown a resonance for UCu_5 that depends on both compressional and shear effects. Total changes in moduli are weak, and the small rounding right at T_N could mask a step discontinuity. The weak softening upon cooling towards T_N is unusual, but would be expected if a similar weak stiffening were seen below. Such an effect should be present for all modes that display effects of the phase transition, but the pure shear modes (not shown) show only a background stiffening precursor on cooling towards the transition. No measurable effect is seen in the ultrasonic attenuation, confirming that we are not observing fluctuations.

The situation for U_2Zn_{17} is also unexpected and very dramatic. A huge softening in the resonances of a small single-crystal flake, shown in Fig. 2, begins sharply at T_N and then continues downward with an inflection point near 5 K. This 10% effect is very hard to understand, especially considering that the normalized slope of the attenuation, shown in the inset, roughly tracks the shear modulus near the transition, but never recovers as the sample is cooled further. Because the resistivity contributes to attenuation, 1/Q could be weakly connected to the coherence effects that produce inflection points [5] for the resistivity at the same temperature as is observed in the sound velocity, and where the attenuation saturates. To cloud the issue further, all this occurs just as spin waves begin to affect the specific heat, and therefore sound propagation.

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