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STRONG DEPRESSION OF MAGNETISM IN HEAVY FERMION  $U_2Zn_{17}$ 

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We have investigated the effects of impurities on the heavy fermion system  $U_2Zn_{17}$ . The Néel temperature of 9.7 K in pure  $U_2Zn_{17}$  is strongly depressed to below 1.5 K with 2% Cu (on the Zn site) or 20% Th (on the U site). The electronic specific heat coefficient is practically independent of impurity concentration above any magnetic ordering temperature.

Heavy fermion systems are characterized by low temperature ( $\approx 10$  K) enhancements of the susceptibility  $\chi$  and of the electronic specific heat coefficient  $\gamma$  on the order of 100, reflecting electronic mass enhancements of the same order. Among the uranium heavy fermion systems,  $UBe_{13}$  [1] and  $UPT_3$  [2] become superconducting,  $UAl_2$  [3] is a spin fluctuator and does not order, and  $UCd_{11}$  [4] and  $U_2Zn_{17}$  [5] are thought to show magnetic order, at the lowest temperatures. Examining  $U_2Zn_{17}$  in more detail, the susceptibility is strongly enhanced over normal metals; it has a broad maximum at 16 K and a sharp decrease below 9.7 K, dropping 25% by 1.5 K. The electronic specific heat  $\gamma$  is about  $0.5 \text{ J}/(\text{mol U K}^2)$  near and above 10 K. At 9.7 K a large  $\lambda$  peak occurs with  $\gamma$  dropping to  $0.19 \text{ J}/(\text{mol U K}^2)$  in the ordered state. The resistivity is  $110 \mu\Omega \text{ cm}$  at room temperature and slowly increases, reaching a maximum at 17 K. Below 9.7 K the resistivity drops by as much as a factor of 80.

Recent neutron diffraction measurements [6] have confirmed that  $U_2Zn_{17}$  magnetically orders at 9.7 K. The magnetic structure is a simple antiferromagnet with the moments in the hexagonal basal plane. The ordered moment is about  $0.6\mu_B$ , much smaller than the  $U 5f^2$  or  $5f^3$  effective moment ( $\approx 3.6\mu_B$ ) and suggesting a strongly itinerant magnet.

One of the major questions about heavy fermion systems is what determines the ground state. This may be probed by applying hydrostatic pressure or by adding impurities to the system under study. The results of the application of pressure on the resistivity of  $U_2Zn_{17}$  are discussed by Thompson et al. [7] The ordering temperature  $T_N$  was found to initially increase at the low rate of 17 mK/kbar and then to saturate at higher pressures. In contrast to these very small changes with pressure, we find that small amounts of impurities, especially on the Zn site, give rise to large changes in the electronic properties of  $U_2Zn_{17}$ .

The pure  $U_2Zn_{17}$  and doped samples were made by placing the constituents in an outgassed BeO or  $ThO_2$  crucible, sealing in a quartz tube, heating to  $1050^\circ\text{C}$ ,

and cooling slowly. The resulting material showed large crystal faces and a plate like morphology. When possible, constituents were pre-arc melted to give a more homogeneous starting material. This was especially important for the Cu substitutions. The susceptibility measurements were obtained in a Faraday magnetometer in an applied field of 1 or 2 T.

The central result of this work, which is shown in fig. 1, is that magnetic order is strongly depressed by non-magnetic impurities in  $U_2Zn_{17}$ . The pure material has a  $T_N$  of 9.7 K and a 25% decrease in  $\chi$  on ordering. With the substitution of 10% of the U by Th,  $T_N$  has dropped to 7.5 K and the ordering appears now as a shallow peak. A much stronger depression of  $T_N$  is seen for substitution of smaller amounts of Cu on the Zn site. For 1% Cu the susceptibility shows a small dip below 8 K, indicative of some small amount of order. But with 2% Cu substitution, the low temperature susceptibility shows no sign of order but instead increases monotonically as the temperature is lowered. Specific heat measurements on this sample indicate only a gradual increase of  $C_p/T (= \gamma)$  from 0.52 to  $0.60 \text{ J}/(\text{mol U K}^2)$  between 10 and 1.5 K. Thus 2% Cu on the Zn site has

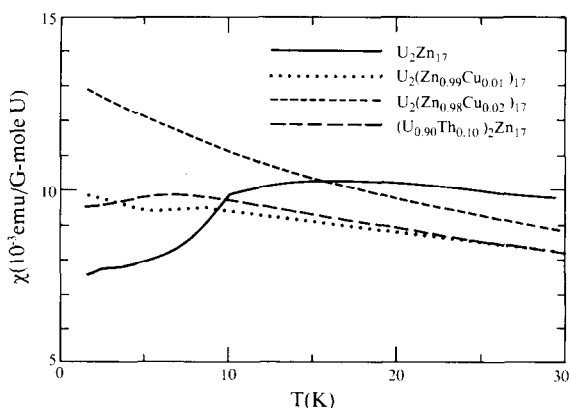


Fig. 1. Susceptibility versus temperature for pure and substituted  $U_2Zn_{17}$ .

depressed  $T_N$  from 9.7 K to below 1.5 K. (AC susceptibility measurements down to 20 mK show no evidence of magnetic order for this composition.)

We thus find that impurities on the Zn site are much more effective in reducing the magnetic ordering temperature than are impurities on the U site. This is somewhat analogous to the effects of impurities on superconductivity in the heavy fermion system  $UBe_{13}$ ; here impurities on the Be site are much more effective than those on the U site in depressing superconductivity [8]. One can speculate that the U–U interactions which result in the heavy fermion properties of this system must be mediated by hybridization with the Zn electrons because the U–U atoms are 4.3 Å apart, too far apart for direct 5f wave function overlap to occur. Thus disturbing the nearest neighbor sites of the U atoms seems to be more effective in destroying magnetism than putting impurities on the next U site.

The resistivity data for both the Cu and the Th substitutions are shown in fig. 2. With Cu, the shape of the  $\rho$  versus  $T$  curve remains unchanged, merely moving to lower temperatures as the Cu concentration is increased. For Th, however, the resistivity changes qualitatively, developing into a sharp increase at low temperature between 4 (not shown) and 10% Th substitution. There is no corresponding feature in the specific heat for the 20% Th sample examined.

These features in the resistivity suggest similarities to the 2.5 K peak in the resistivity of  $UBe_{13}$  [9]. This anomaly may move up or down in temperature depending on the impurity atom added and is not clearly associated with any other phenomena [10]. For pure  $U_2Zn_{17}$ , the large drop in resistivity below 10 K is associated with magnetic ordering; what the resistivity features are associated with in the case of Th substitutions is less clear.

In summary, we have examined some of the effects of impurities on the low temperature properties of  $U_2Zn_{17}$ . All substitutions depressed the Néel temperature with impurities on the Zn site being more effective. The  $\gamma$  values remained large and virtually unchanged above any  $T_N$ . The susceptibility was more strongly affected by impurities, and its variation depended on the amount and location of the impurity. The low temperature resistivity was also strongly affected by

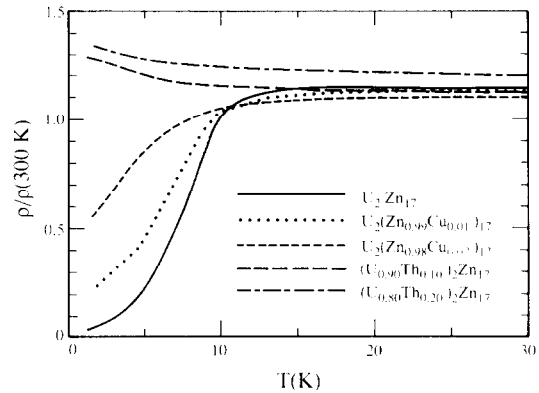


Fig. 2. Resistivity (normalized at room temperature) versus temperature for pure and substituted  $U_2Zn_{17}$ .

impurities, the details of which are not currently understood.

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