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ELECTRICAL RESISTIVITY OF $U_{1-x}M_xBe_{13}$ UNDER PRESSURE

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Measurements of the electrical resistivity of $U_{1-x}Th_xBe_{13}$ compounds as a function of pressure provide a possible explanation for the unusual behavior of these materials.

Thorium substitution into $U_{1-x}Th_xBe_{13}$ affects both the superconducting and normal state properties [1]. Particularly interesting is the appearance of a cusp in the superconducting transition temperature T_c at $x = 0.0172$ and a second phase transition at T_{c2}, below T_c, for $0.019 < x < 0.04$ [2]. Muon spin rotation experiments [3] detect a magnetic moment of $\sim 10^{-3}\mu_B/U$ for $T < T_{c2}$, suggesting that this transition is magnetic or that it is associated with an exotic superconducting phase that has a magnetic moment. The former interpretation is supported by ultrasonic data [4] and the latter is argued for from pressure measurements [5] of T_c vs. x.

Previously we have shown [6] that pressure modifies the temperature dependence of the resistivity ρ of pure UBe_{13}, particularly at low temperatures where ρ reaches a maximum at $T = T_{max} \approx 2.5$ K. Further, there appears to be an inverse correlation [7] between T_{max} and the pressure dependent electronic specific heat γ(P), i.e. $\gamma(P) \propto 1/T_{max}(P)$. Ambient pressure specific heat and resistivity measurements on UBe_{13} and $U_{1-x}Th_xBe_{13}$ also show that $\gamma(T \to 0)$ depends sensitively

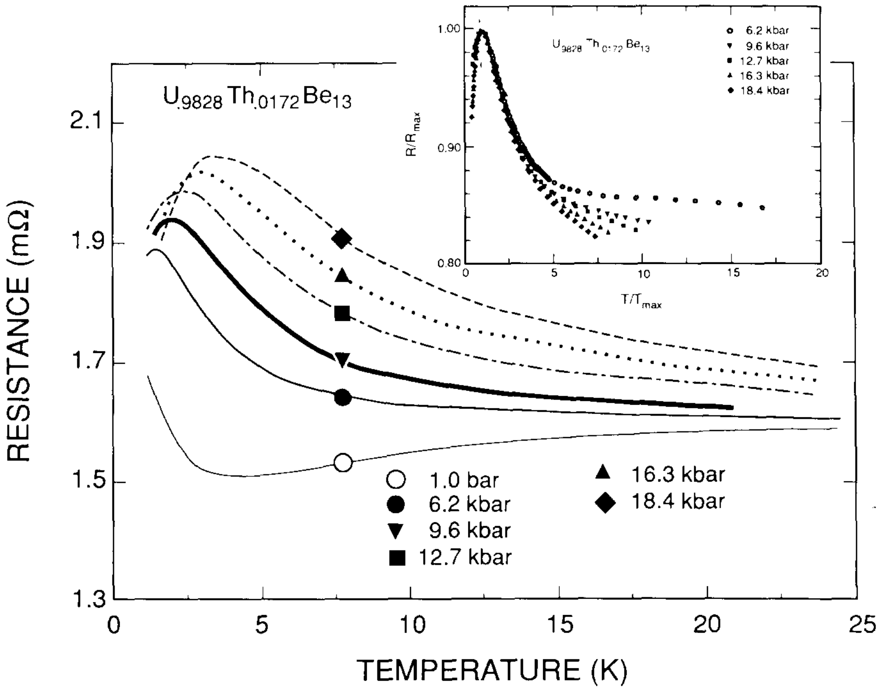

Fig. 1. Electrical resistance R of $U_{0.9828}Th_{0.0172}Be_{13}$ at various pressures as a function of temperature T. The inset shows the same data but now the resistance has been normalized by its maximum value R_{max} and the temperature by the value at which R_{max} occurs.

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on the unit cell volume [8] with γ increasing and T_{max} decreasing as the volume increases, which is the case with Th substitution. Here we report pressure studies on the resistivity of $U_{1-x}Th_xBe_{13}$ for $x = 0$, 0.0093, 0.0172, 0.0340 and 0.0536.

Details of the sample preparation and procedure for resistivity measurements under modest hydrostatic pressures have been described earlier and will not be reiterated here.

As an example of our results, we show in fig. 1 the effect of pressure on the resistance R of $U_{0.9828}Th_{0.0172}Be_{13}$, the composition where the cusp in $T_c(x)$ appears. At ambient pressure, there is no peak in ρ for $T \geqslant 1.2$ K, but for $P \geqslant 6.2$ kbar, T_{max} appears at low temperatures and is observed to move to higher temperatures with pressure. As is true for UBe_{13} [6], we find that the curves of fig. 1 can be scaled onto each other by normalizing R by $R_{max}(R_{max} = R(T_{max}))$ and T by T_{max} (fig. 1 inset) and further that the scaled curves for both $x = 0$ and 0.0172 compare favorably. This suggests that R_{max} has the same physical origin in both samples. For $x = 0.0340$ and 0.0536, no peak in $\rho(T)$ was found above 1.2 K up to the highest pressures studied, 14.9 and 17.2 kbar respectively. However, qualitatively we can scale all data for $0 \leqslant x \leqslant 0.0536$ onto each other by assuming that 1 a/o Th produces a negative chemical pressure of ~ 7 kbar, a value much larger than expected (~ 0.45 kbar/a/o) on the basis of lattice parameter changes [1] alone. This implies that Th substitution does more than simply expand the lattice.

Fig. 2 compares the pressure dependence of T_{max} for UBe_{13} to that of $U_{1-x}Th_xBe_{13}$ with $x = 0.0093$ and 0.0172. In the case of UBe_{13}, dT_{max}/dP is linear from $P = 0$; however, in the Th-doped samples there appears to be two regions of differing dT_{max}/dP. For $x = 0.0093$, the change in slope occurs for $P \approx 6$ kbar; whereas, for $x = 0.0172$ the slope change takes place near 16 kbar. The high-pressure slopes of both are close to that of UBe_{13}. Further, the pressure at which the slope change occurs is approximately that pressure required to compensate the negative chemical pressure produced by Th substitution.

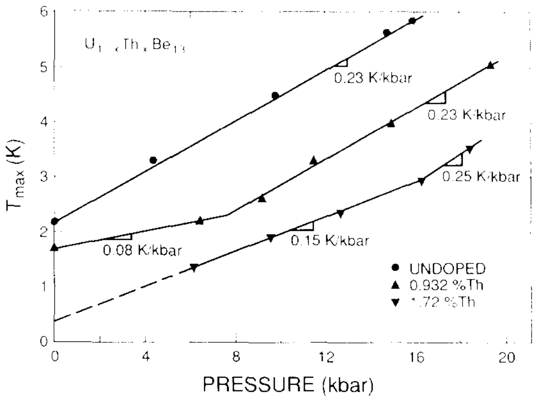

Fig. 2. Temperature at which the resistance maximum appears T_{max} as a function of pressure for $U_{1-x}Th_xBe_{13}$ with $x = 0$, 0.0093 and 0.0172.

Pressure measurements of T_c for $x = 0.019$ and 0.026 reveal a "kink" in $T_c(P)$ at the temperature-pressure points (0.48 K, 1.3 kbar) and (0.20 K, 5.2 kbar) respectively [5]. From an extrapolation of our T_{max} (P) vs. x data, we can estimate the temperature at which T_{max} should appear for (x, P) corresponding to those producing the kink in $T_c(P)$. Within the estimated uncertainty in both experiments, $T_{max}(x, P)$ is coincident with the kink in $T_c(x, P)$, suggesting that with pressure the kink arises from the passage of T_{max} from below T_c through the $T_c(x, P)$ phase boundary.

That T_{max} be below T_c appears to be a necessary condition for the development of the second phase transition. However, T_{max} clearly is not equivalent to T_{c2} because $dT_{max}/dP > 0$ but $dT_{c2}/dP < 0$ [9]. The variation of $\rho(T)$ and the increase of $\gamma(T \to 0)$ at ambient pressure with x suggest that the single-site Kondo temperature T_K is a decreasing function of x, thereby enabling magnetic interactions to become more significant. A possible explanation for the second phase transition is that it originates from magnetic interactions made possible by the lowered T_K with Th substitution. Applied pressure would raise T_K relatively rapidly, producing $dT_{max}/dP > 0$ but also suppressing magnetic correlations responsible for the second phase transition, i.e. $dT_{c2}/dP < 0$. This simple picture also would predict that B substitution for Be could produce a second transition below T_c, as appears to be the case [10]. Certainly, this interesting system requires much further study before it is well-understood.

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