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Specific Heat of $(U_{0.97}Th_{0.03})Be_{13}$ under Pressure*

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The specific heat, C , of $(U_{0.97}Th_{0.03})Be_{13}$ has been measured for $0.1 \leq T \leq 1K$ and $1.6 \leq P \leq 7.7$ kbar, and for $0.1 \leq T \leq 20K$ with $P=0$. For $T > 8K$ both the pure and Th substituted samples have essentially the same C . The peaks in C/T at 0.33 and 0.54K for $P=0$ are suppressed and shifted to lower T by pressure. Anomalies in C/T can be correlated to corresponding rapid changes in magnetic susceptibility, χ . Rapid suppression of the peaks and shift of T_c to lower values is in marked contrast to the behavior found for pure UBe_{13} whose single peak amplitude decreases approximately linearly with P to about 60% at 9.3 kbar. The broad "shoulder" in C/T near 2K that is found for UBe_{13} , but not for any other heavy-fermion compound, HFC, is completely suppressed in the Th substituted sample.

Substitution of non-magnetic Th on U sites in UBe_{13} , $(U_{1-x}Th_x)Be_{13}$, produces unexpected and complex behavior in the superconducting region below 1K. In addition to the anomalous non-monotonic decrease of the superconducting transition temperature, T_c , with increasing Th content, there is the appearance of a second peak in C for $0.0175 < x < 0.04$ which is not due to a second phase or inhomogeneities [1]. For this range of x , T_c is nearly constant at 0.6K. Substitution of other impurities for U and Be produces a monotonic decrease of T_c , with no special depression of T_c associated with a magnetic moment on the impurity [2-4]. The unique effect of Th substitution on UBe_{13} over a limited range of x has been interpreted both as an antiferromagnetic transition [5] and as a transition between two anisotropic superconducting states [6]. Several attempts to confirm the presence of magnetic ordering in the $(U_{1-x}Th_x)Be_{13}$ system have failed [7,8], while the effect on T_c of magnetic Gd substituted for U ($x=0.03$) supports the suggestion of two different superconducting phases [2].

Measurements of the P -dependence of properties is a particularly fruitful approach for an HFC because the extreme pressure sensitivity of the 4f and 5f-electrons involved in the phenomena produces large effects at readily attainable pressures.

Recently χ of the $(U_{1-x}Th_x)Be_{13}$ system has been measured in the range $0 \leq P \leq 12$ kbar below 1K for $0 \leq x \leq 0.06$ [9]. Two distinct regions of superconductivity are present for $P > 9$ kbar, which are separated by a range of x where superconductivity does not occur. Except for $x=0.06$, T_c , determined from changes in χ , decreases monotonically as P increases.

The $(U_{0.9697}Th_{0.0303})Be_{13}$ sample for the specific heat measurements weighed 1.673g and consisted of five right circular cylinders (approximately 6.4mm dia. x 2.4mm long) sparkcut from the center of an arc-melted, unannealed, polycrystalline "button" prepared as described previously [10]. They were placed in a pressure cell [11] and surrounded by AgCl to act as a pressure transmitting medium. A thin Sn plate on top of the sample stack and a Pb plate on the bottom served as superconducting manometers. The pressure gradient across the stack was $\sim 15\%$. For all T and P in the range of the measurements, the heat capacity of the sample was $>50\%$ of the total.

Fig. 1. C/T vs T for $(U_{0.97}Th_{0.03})Be_{13}$.

Measurements of the properties of materials as a function of pressure, P , provides an additional dimension in which to make comparisons with model calculations or theory. They also provide a straightforward basis for establishing correlations between superconductivity and magnetism without the complications of interpretation associated with measurements on a series of structurally and chemically different compounds.

Fig. 2. T_c vs P for $(U_{0.97}Th_{0.03})Be_{13}$ as determined from χ and C measurements.

Figure 1 is a plot of C/T vs T below 1K in the range $0 \leq P \leq 7.7$ kbar. A vertical bar for a particular P in Fig. 1 indicates T at the midpoint of the rapid change in χ [9], and is interpreted as T_c . At $P=0$, C/T has a finite intercept at $T=0$, which in the case of UBe_{13} has been shown [12] to be sample dependent rather than an intrinsic property of this material. For $0.6 \leq T \leq 1K$, $C(P)/C(0)$ varies by a relatively small amount. Over some of this range $C(P)$ increases with respect to $C(0)$ for $P \leq 3.9$ kbar, while at higher P , $C(P)$ decreases over the entire range. The peaks in C/T at 0.33 and 0.54K for $P=0$ are strongly suppressed, broadened, and shifted to lower T for $P>0$. At 1.6 kbar the peaks are barely resolved at 0.26 and 0.43K. Only a single broad maximum is observed for $P=3.9$ kbar with an onset of the anomaly near 0.4K. For $P=6.7$ kbar only a very small anomaly remains, near 0.15K. At 7.7 kbar an apparently new feature develops -- a small maximum centered near 0.17K. This anomaly may be present at lower pressures but is obscured by the other anomalies, and it could be an impurity effect.

Fig. 3. C vs $\log T$ for UBe_{13} and $(U_{0.97}Th_{0.03})Be_{13}$ at $P=0$.

Figure 2 is a plot of T_c vs P . Values of T_c from Ref. [9] are the midpoints of the changes in χ taken from Fig. 1 and are displayed as filled circles. From the C measurements, T_c is taken as the midpoint of the rise in C/T at the anomaly and is graphed as an open square. During the present measurements, χ was measured at 1.6 kbar. The T_c derived from it is shown as a filled square with the vertical bar indicating the transition width, and is comparable to other data [9]. A satisfactory correlation exists between T_c determined by χ and C . Variation of the temperature of the lower temperature peak with P is more difficult to define. Except for 0 and 1.6 kbar there is no obvious indication of an anomaly and for $P>3.9$ kbar it is presumably below the range of T investigated, and/or obscured by broadening and superposition of the two anomalies. If the maximum of the lower peak in C/T is used to mark the second transition, it is represented by open triangles in Fig. 2. (The dashed curve is drawn parallel to the solid curve.) The average

dT_c/dP between 0 and 1 kbar is $-40mK/kbar$ for both transitions. dT_c/dP increases to $-80mK/kbar$ at 4 kbar where it remains essentially constant to 8 kbar for the higher T transition. These rates of decrease of T_c with P are in contrast to the constant and lower rate of $-24mK/kbar$ for UBe_{13} , and the 60% decrease in peak amplitude from 0 to 9.3 kbar.

In Fig. 3, C is plotted vs $\log T$ for both UBe_{13} and $(U_{0.97}Th_{0.03})Be_{13}$. The broad maximum near 2K for UBe_{13} has been completely suppressed by the Th substitution. Substitution of Th, Lu and Sc for U gave similar results in an earlier investigation [4]. This feature in C has been interpreted as due to development of coherence in a Kondo lattice [13]. Suppression of the anomaly by a non-magnetic impurity is consistent with this idea. Above $\sim 8K$, C for both the pure and substituted samples are essentially identical as found previously [4].

REFERENCES

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- 1) H.R. Ott, H. Rudigier, Z. Fisk and J.L. Smith, Phys. Rev. **B31**, 1651 (1985).
- 2) J.L. Smith, Z. Fisk, J.O. Willis, H.R. Ott, S.E. Lambert, Y. Dalichaouch and M.B. Maple, J. Magn. Magn. Mat. **63-64**, 464 (1987).
- 3) Z. Fisk, H.R. Ott and J.L. Smith, "Sixth Conference on Nonlinearities in Condensed Matter", Los Alamos, May 1986, to be published by Springer-Verlag.
- 4) H.R. Ott, H. Rudigier, E. Felder, Z. Fisk and J.L. Smith, Phys. Rev. **B33**, 126 (1986).
- 5) B. Batlogg, D. Bishop, B. Golding, C.M. Varma, Z. Fisk, J.L. Smith and H.R. Ott, Phys. Rev. Lett. **55**, 1319 (1985).
- 6) R. Joynt, T.M. Rice and K. Ueda, Phys. Rev. Lett. **56**, 1412 (1986).
- 7) Neutron scattering: H. Mook, private communication, quoted from Ref. [3].
- 8) NMR: D.E. McLaughlin, C. Tien, W.G. Clark, M.D. Lan, Z. Fisk, J.L. Smith and H.R. Ott, Phys. Rev. Lett. **53**, 1833 (1984).
- 9) S.E. Lambert, Y. Dalichaouch, M.B. Maple, J.L. Smith and Z. Fisk, Phys. Rev. Lett. **57**, 1623 (1986).
- 10) J.L. Smith, Z. Fisk, J.O. Willis, A.L. Giorgi, R.B. Roof, H.R. Ott, H. Rudigier and E. Felder, Physica **135B**, 3 (1985).
- 11) D.B. McWhan, J.P. Remeika, S.D. Bader, B.B. Triplett and N.E. Phillips, Phys. Rev. **B7**, 3079 (1973).
- 12) R.A. Fisher, S.E. Lacy, C. Marcenat, J.A. Olsen, N.E. Phillips, Z. Fisk, A.L. Giorgi, J.L. Smith and G.R. Stewart, "Fifth International Conference on Valence Fluctuations", Bangalore, India, Jan. 1987, to be published.
- 13) H.R. Ott, H. Rudigier, Z. Fisk and J.L. Smith, "Moment Formation in Solids", ed. W.J.L. Buyers, Plenum, NY (1984), p. 305.