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CONF 870142--6

LA-UR-87-309

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LA-UR--87-309

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TITLE: LOW-TEMPERATURE SPECIFIC HEAT OF UBe_{13}

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SUBMITTED TO: Fifth International Conference on Valence Fluctuations January 5-9, 1987, Bangalore, India

LOW-TEMPERATURE SPECIFIC HEAT OF UBe_{13}

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The specific heats (C) of the heavy-fermion superconductors, $CeCu_2Si_2$, UPt_3 and UBe_{13}, show significant sample-to-sample variations in both the normal and superconducting states (C_n and C_s, respectively). For some samples, $C_s/T \neq 0$ at T=0. This has been interpreted as evidence for gapless superconductivity [1-3], and, in the case of UPt_3, as evidence of a gap over part of the Fermi surface [4], but could also indicate simply that some of the material remains normal. Measurements of C are reported here for four polycrystalline samples of UBe_{13} of differing quality, gauged by transition temperature (T_c) and width (δT_c). There is a strong correlation of C_s/T at T=0 with T_c and δT_c. The data also give some information on extrapolation of C_n to T=0.

Fig. 1 shows C/T below 1K in magnetic fields (H) of 0 and 7.5T. Cubic

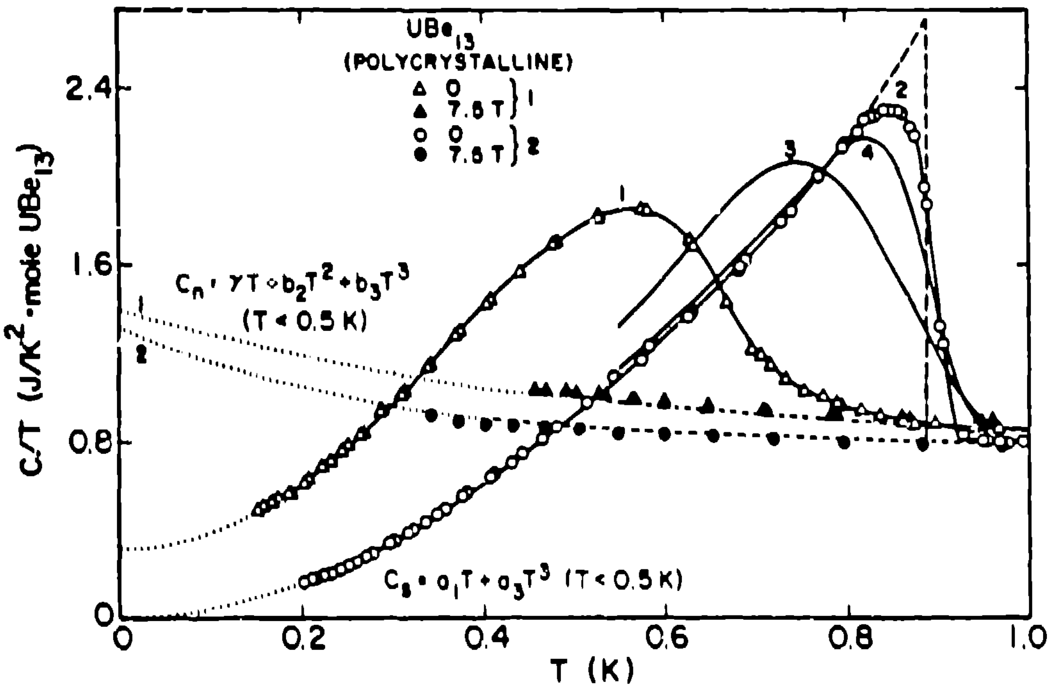

Fig. 1. C for four samples of UBe_{13} below 1K.

spline fits of the H=0 data for samples 3 and 4 are displayed near and below T_c. Above T_c, 7.5T has only a small effect on C; below T_c it suppresses the transition at the lowest T investigated, 0.35K. The light dashed curves represent probable values of C_n/T at H=0. They are parallel to C/T at 7.5T, but shifted by the small (barely perceptible) amount necessary to coincide with C/T at H=0 just above T_c. The dotted extrapolations to T=0 are by the 3-term polynominals indicated in Fig. 1, with two coefficients chosen to force a match to the dashed curves and the third chosen to give the same high-T entropy as that derived from C_s. Values of γ derived by this process are given in Table 1 for all four samples. Just above T_c, C_n/T is nearly constant but increases slowly with decreasing T. The experimental data display a more rapid increase below T_c, and a still more rapid increase is required below 0.35K (in the region of the extrapolation) to conserve entropy.

The heavy dashed vertical line for sample 2 is the idealized, entropy-conserving construction for a sharp transition at T_c. (Similar constructions for the other samples are omitted for clarity.) Table 1 lists values of T_c and δT_c, the difference between T_c and T at the onset of superconductivity.

C_s data at H=0 for the four samples are plotted in Fig. 2. From least-squares fits, the straight lines in the insert, it is evident that C_s for all samples is well represented by $C_s = a_1T + a_3T^3$. (Table 1 lists a_1 and a_3.) The positive deviation from this form at low-T for sample 4 has a T^{-2} dependence and may reflect a contribution from impurities. A small upturn of C/T at low-T for sample 2 is perhaps also due to impurities, but the effect is too small to permit analysis of the T dependence. The solid curves in Fig. 2 represent $a_1T + a_3T^3$ plus the additional T^{-2} term for sample 4. The strongly sample dependent a_1 correlates with T_c and δT_c: For samples 2 and 4, with the higher T_c and lower δT_c, $a_1 = 0$. We conclude that the linear term is not an intrinsic property of UBe_{13}. The T^3 dependence of C_s, which contrasts with

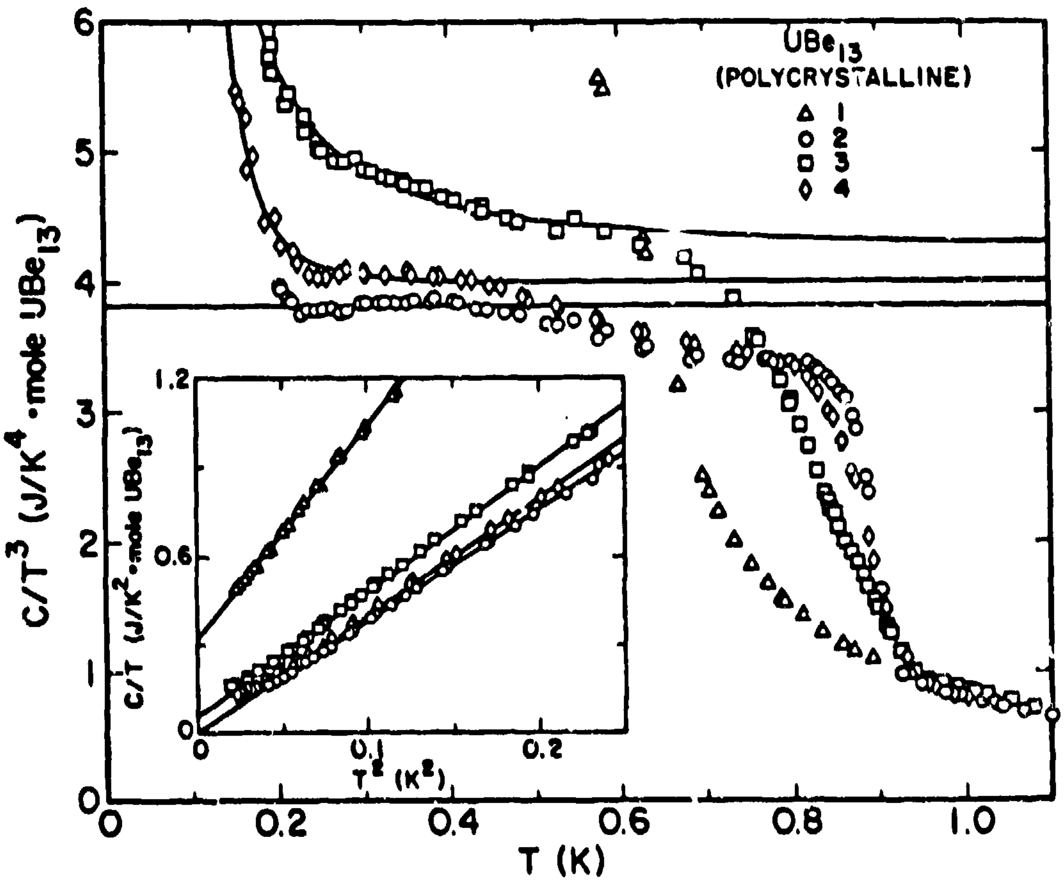

Fig. 2. Limiting low temperature behavior of C for UBe_{13}.

Table 1. Properties Characterizing Four UBe_{13} Samples below T_c. Units: a_1 and γ in $J/K^2\cdot mole$; a_3 in $J/K^4\cdot mole$; C(1K) and S(1K) in J/K·mole.

Samples	δT_c(K)	T_c(K)	γ	a_1	a_3	f_s	r	C(1K)	S(1K)
2	0.03	0.89	1.31	0	3.82	1	2.4	0.789	0.904
4	0.07	0.89	1.40	0	4.00	1	2.1	0.790	0.891
3	0.11	0.84	1.34	0.06	4.25	0.96	2.0	0.861	0.971
1	0.15	0.68	1.39	0.31	7.32	0.78	2.0	0.855	1.058

the BCS exponential dependence on T, has been observed previously for UBe_{13}, and has been interpreted in terms of p-wave pairing [5]. Power laws in T for C_s have also been found for $CeCu_2Si_2$ and UPt_3 and have been interpreted as arising from points or lines on the Fermi surface with zero gap [1-3]. In addition to the power law for C_s, there is a new feature for samples 2 and 4 -- a small but significant departure from T^3 behavior near 0.5K, corresponding approximately, especially for sample 2, to a change in the value of a_3. This effect is also present for a sample studied by the Darmstadt group [2] (Fig. 7b). The fact that the same effect is seen in three samples from two separate sources, and in two laboratories with independent measuring techniques, demonstrates that it is a real, intrinsic property of UBe_{13}. (Samples 1 and 3 do not show this "transition" region, perhaps because of a lowered quality.) An intriguing possibility is that this feature is related to the second transition [6] in $(U,Th)Be_{13}$ that persists for UBe_{13}.

BCS theory gives $r \equiv [(C_s-C_n)/C_n(T_c)] = 1.43$. Taking "ideal" values of C_s-C_n (derived from constructions like that for sample 2 in Fig. 1), r = 2.4 for sample 2, close to reported values [2,5] and typical for strong coupling superconductors. For sample 4, r = 2.1. For samples 1 and 3, r < 2, but, assuming the a_1T term in C_s is due to material remaining normal, r would be corrected to 2.0 for both. The superconducting fraction of the sample at T=0, $f_s \equiv 1-a_1/\gamma$, and corrected values of r are given in Table 1.

Fig. 3 shows C_n/T vs. T from 1 to 20K for samples 1 and 2 at T=0, and sample 2 at 7.5K. In the region of the broad maximum in C_n (1-5K) the samples differ somewhat, while above 5K, C_n is nearly the same for each. Between 5

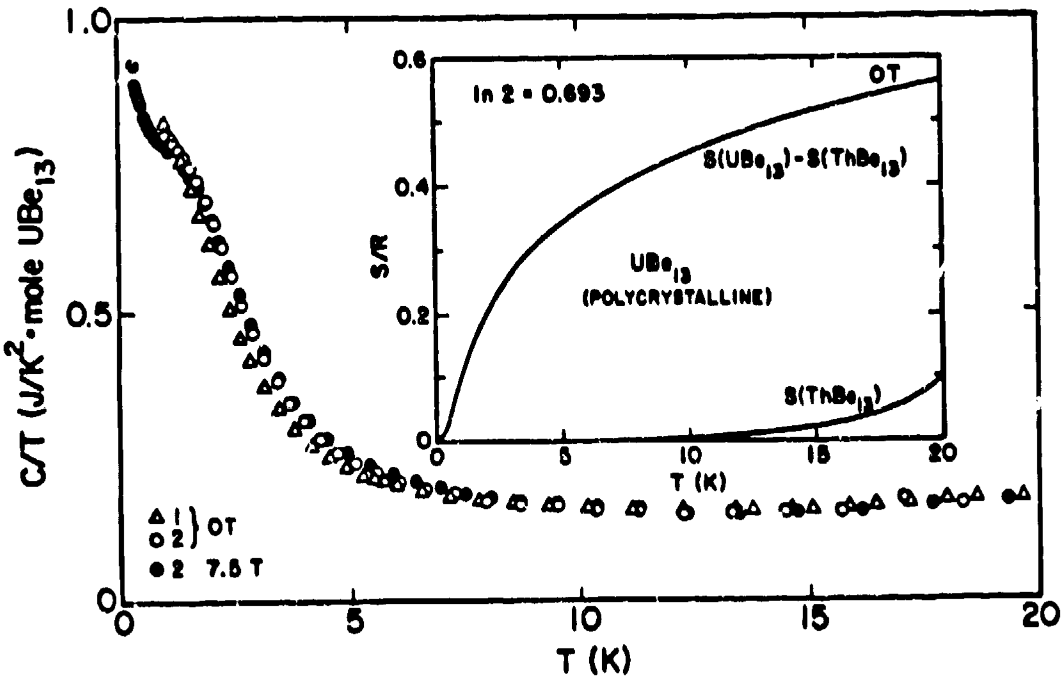

Fig. 3. C and S for UBe_{13} at 0 and 7.5T to 20K.

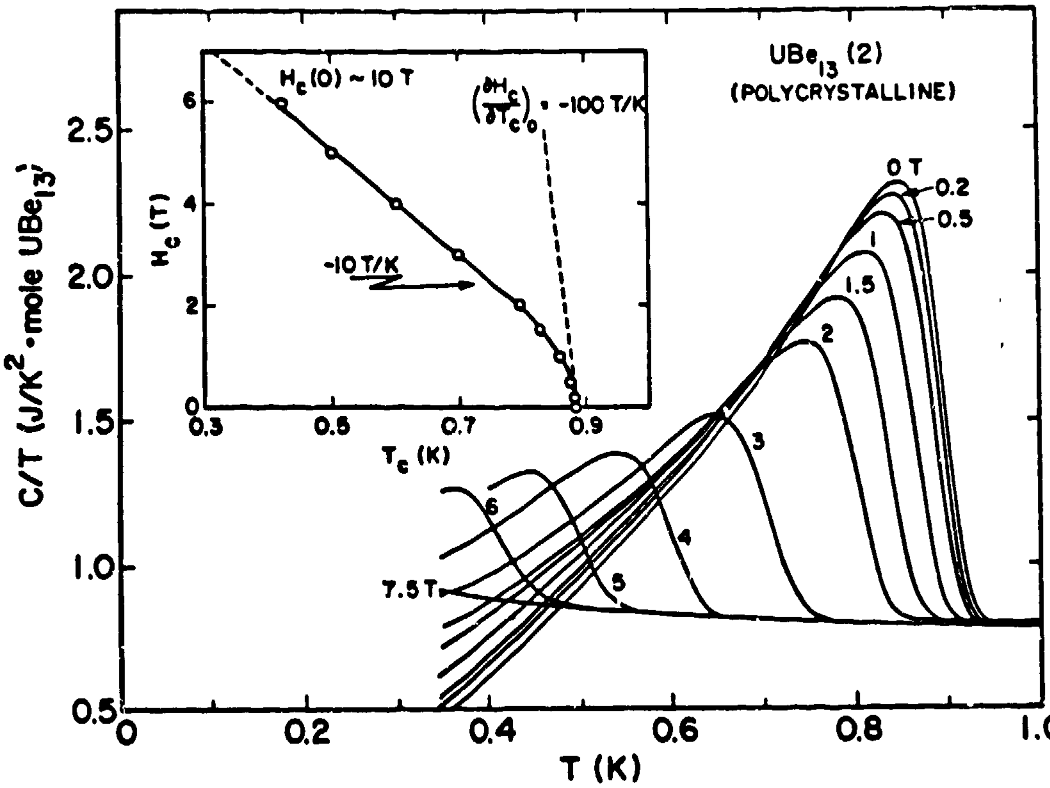

Fig. 4. H_c vs. T_c for UBe_{13} as measured by C in fields to 7.5T.

and 20K, C_n/T has a weak T dependence with a minimum near 12K. Stewart [1] has reviewed measurements of C in this T-range. The insert shows the electronic entropy calculated by subtracting the entropy for $ThBe_{13}$ [7].

Fig. 4 shows cubic spline fits of C/T vs. T for sample 2 in fields to 7.5T. (Precision of the data is similar to that in Fig. 1.) T_c vs. H_c is shown in the insert — T_c was taken as T at the midpoint of the transition, and these values of T_c are not equal to those in Table 1. Initially $(\partial H_c/\partial T_c)$ is -100T/K (at least) and for higher H is linear at -10T/K. At T=0, H_c extrapolates to 10T. Similar calorimetric results have been reported [8].

Work at Berkeley was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy under Contract DE-AC03-76SF00098. Work at Los Alamos was supported by the U.S. Department of Energy.

REFERENCES

1. G. R. Stewart, Rev. Mod. Phys. 56: 755 (1984).
2. F. Steglich, "Theory of Heavy Fermions and Valence Fluctuations", ed. T. Kasuya and T. Saso, Springer Series in Solid State Sciences 62: 23 (1985).
3. Z. Fisk, H. R. Ott, T. M. Rice and J. L. Smith, Nature 320: 6057 (1986).
4. T. Oguchi, A.J. Freeman and G.W. Crabtree (preprint).
5. H. R. Ott, H. Rudigier, T. M. Rice, K. Ueda, Z. Fisk and J. L. Smith, Phys. Rev. Lett. 52: 1915 (1984).
6. H. R. Ott, H. Rudigier, Z. Fisk and J. L. Smith, Phys. Rev. B31: 1651 (1985).
7. E. Bucher, J. P. Maita, G. W. Hull, R. C. Fulton and A. S. Cooper, Phys. Rev. B11: 440 (1975).
8. U. Rauchschwalde, U. Ahlheim, F. Steglich, D. Rainer and J. J. M. Franse, Z. Phys. B60: 379 (1985). H. R. Ott, H. Rudigier, E. Felder, Z. Fisk and J. L. Smith, Phys. Rev. B33: 126 (1986).