Title
Impurities in UBe13

Journal
Journal of Magnetism and Magnetic Materials, 63(C)

ISSN
0304-8853

Authors
Smith, JL
Fisk, Z
Willis, JO
et al.

Publication Date
1987

DOI
10.1016/0304-8853(87)90637-8

Journal of Magnetism and Magnetic Materials 63 & 64 (1987) 464–466
North-Holland, Amsterdam

IMPURITIES IN UBe_{13}

J L SMITH, Z FISK, J O WILLIS, H R OTT*, S E LAMBERT⁺, Y DALICHAOUCH⁺ and M B MAPLE⁺

Materials Science and Technology Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA
**Laboratorium fur Festkorperphysik, Eidgenossische Technische Hochschule Honggerberg 8093 Zurich, Switzerland*
⁺Department of Physics and Institute of Pure and Applied Physical Sciences, University of California, San Diego La Jolla CA 92093, USA

Gadolinium impurities in UBe_{13} depress the T_c at an initial rate of −0.40 K/%, while in $Th_{0.029}U_{0.971}Be_{13}$ the initial rate is only −0.19 K/% This strongly suggests two different superconducting states Further data on thorium depressions and critical fields are presented

Thorium impurities, which substitute on the uranium sites, in the heavy-fermion superconductor UBe_{13} lead to a non-monotonic depression of T_c [1] In the anomalous region, for 1.75% < Th% < 6%, a second heat capacity feature shows up at a temperature below the superconducting transition [2] This has been interpreted both as an antiferromagnetic transition [3] and as a transition between two different anisotropic superconducting states [4] In this latter paper, Joynt et al propose a phase diagram for $Th_xU_{1-x}Be_{13}$ that contains three superconducting phases While the uncertainty over interpretation of the second transition in the thorium-doped material continues, we decided to investigate by the more common measurements on superconductors whether at least two different superconducting phases could be demonstrated (A and B in ref [4]) Their existence is only possible in an exotic superconductor Indeed, very different pressure dependences were subsequently observed in the two different regions [5] It was noted in ref [1] that there was little difference in T_c depressions for magnetic and non-magnetic rare earth impurities We have now investigated this for gadolinium and also have looked at the effects of gadolinium in both superconducting regions of the thorium-doped systems We have made preliminary critical field measurements as well

For all of the results reported here, we measured polycrystalline samples that we prepared by arc-melting as described in ref [1] Fig 1 reproduces earlier data on T_c's in $Th_xU_{1-x}Be_{13}$ [1,6] and includes data on all samples that we have made in the concentration range of particular interest Many of the points represent only the highest T_c found in many measurements of different pieces of the same sample We believe that the increased scatter around the relative minimum at 1.75% Th is a reflection of the sensitivity of the precise cross-over between the two superconducting phases to the homogeneity of the samples The difference in thorium concentration between many of the

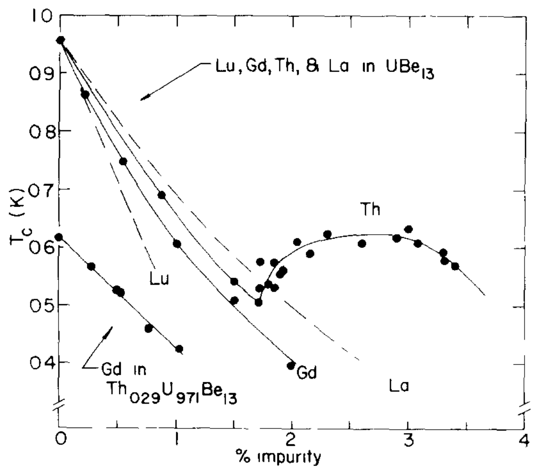

Fig 1 The superconductivity onset temperatures of various impurity concentrations in UBe_{13} plotted as a function of per cent replacement on the non-beryllium atomic sites

samples is only a few parts in 10^5 We have now also confirmed the depth of this minimum (0 5 K) by heat capacity measurements

The gadolinium depression curve in fig 1 falls between those of lutetium and lanthanium taken from ref [1] A few samples prepared for EPR measurements [7] containing less than 0 5% of Dy and Er fall in between the lutetium and gadolinium curves This gadolinium depression is a remarkably slow one for any superconductor [8] and strongly suggests a non s-state pairing Indeed, all of the depression data we have taken for the 4f-electron elements (except cerium) can be correlated with only a consideration of the lattice parameter changes and is independent of 4f magnetic moments This is also consistent with non s-state pairing

To investigate the question of another superconducting phase for Th% > 1 75, we prepared samples of the form $Gd_x(Th_{0\,02900\pm0\,00003}U_{0\,971})_{1-x}Be_{13}$ The T_c's for these, where we are clearly in the B phase of ref [4], are shown in fig 1 The depression rate is much lower than for pure UBe_{13} The dT_c/dx at $x = 0$ is estimated to be $-0\,40$ K/% for pure UBe_{13} and $-0\,19$ K/% for 2 9% Th doping This cannot be explained by lattice parameter changes because gadolinium yields almost no changes in UBe_{13} compared to the other impurities [1,6] Disorder or density of states arguments seem unlikely explanations in light of all of the data in the figure The best explanation is that there are indeed two different superconductors separated by the 1 75% Th minimum, as is also concluded from the pressure effects [5] Critical field measurements are needed to clearly sort out magnetic effects in the Th 2 9% samples from other possibilities

Fig 2 shows a preliminary H_{c2} measurement on $Gd_{0\,010}U_{0\,990}Be_{13}$ as well as those for UBe_{13} [9] and $Th_{0\,033}U_{0\,967}Be_{13}$ [10] Very different behavior is observed in these cases illustrated by the data The $H_{c2}(T)$ curve for UBe_{13} is anomalous in several respects First, the large value of the electron effective mass is reflected in the enormous initial slope $(-dH_{c2}/dT)_{T_c}$ As the applied field H increases, strong curvature of $H_{c2}(T)$ is observed, followed at higher fields by a linear variation with temperature A satisfactory explanation for this unusual behavior has not been presented Substitution of 3 31% Th and 1 02% Gd for U in UBe_{13} suppresses T_c to approximately the same value when $H = 0$ The shape of $H_{c2}(T)$ is unchanged by the presence of thorium impurities, but is strongly altered in low fields by gadolinium impurities In particular, the initial slope is considerably reduced, and the strong curvature seen in low fields in the other data is not present An analysis of data for several gadolinium concentrations up to $x = 2\%$ using the conventional theory of type II superconductivity shows that the behavior in low fields can be explained [11] by the influence of the magnetized gadolinium spins on the conduction electron spins For $H \gtrsim 10$ kG, the gadolinium moments are completely aligned by the applied magnetic field, and the behavior characteristic of pure UBe_{13} is recovered Measurements on the $Gd_x(Th_{0\,029}U_{0\,971})_{1-x}UBe_{13}$ samples are in progress

Gadolinium spins have remarkably little effect on this heavy Fermion superconductor and lead to a strong suggestion that there are at least two different superconducting phases in the $Th_xU_{1-x}Be_{13}$ system This is more evidence for unconventional superconductivity [12]

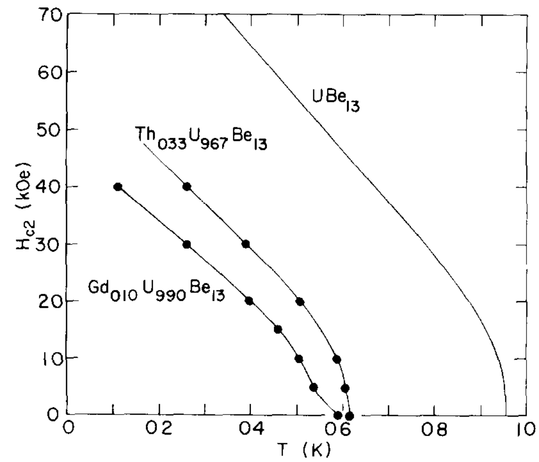

Fig 2 The superconducting critical fields for three materials with the superconducting temperatures taken from the 10% onset of the ac susceptibility transitions for $Gd_{0\,01}U_{0\,99}Be_{13}$ and the mid point of the resistive transitions for the other two

Work at Los Alamos was performed under the auspices of the US Department of Energy, Office of Basic Energy Sciences, Division of Materials Science Work in Zurich was supported by the Schweizerische Nationalfonds zur Forderung der Wissenschaftlichen Forschung Work at La Jolla was also supported by the Department of Energy under Grant No DE-FG03-86ER45230

References

[1] J L Smith, Z Fisk, J O Willis, A L Giorgi, R B Roof, H R Ott, H Rudigier and E Felder, Physica 135B (1985) 3

[2] H R Ott, H Rudigier, Z Fisk and J L Smith, Phys Rev B31 (1985) 1651

[3] B Batlogg, D Bishop, B Golding, C M Varma, Z Fisk, J L Smith and H R Ott, Phys Rev Lett 55 (1985) 1319

[4] R Joynt, T M Rice and K Ueda, Phys Rev Lett 56 (1986) 1412

[5] S E Lambert, Y Dalichaouch, M B Maple, J L Smith and Z Fisk, Phys Rev Lett 57 (1986) 1623

[6] J L Smith, Z Fisk, J O Willis, B Batlogg and H R Ott J Appl Phys 55 (1984) 1996

[7] F Gandra, S Schultz, S B Oseroff, Z Fisk and J L Smith, Phys Rev Lett 55 (1985) 2719

[8] M B Maple, in Magnetism, Vol V, ed H Suhl (Academic, New York, 1973) p 289

[9] M B Maple, J W Chen, S E Lambert Z Fisk, J L Smith, H R Ott, J S Brooks and M J Naughton, Phys Rev Lett 54 (1985) 477

[10] J W Chen, S E Lambert, M B Maple, M J Naughton, J S Brooks, Z Fisk, J L Smith and H R Ott, J Appl Phys 57 (1985) 3076

[11] Y Dalichaouch, S E Lambert, M B Maple, J L Smith and Z Fisk, unpublished

[12] Z Fisk, H R Ott, T M Rice and J L Smith, Nature 320 (1986) 124