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Title

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Journal

Physica B Condensed Matter, 199(C)

ISSN

0921-4526

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[et al.](#)

Publication Date

1994-04-01

DOI

10.1016/0921-4526(94)91739-6

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Physica B 199&200 (1994) 67-69

PHYSICA B

Investigations of the nature of the 0.4 K phase transition in YbBiPt

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Abstract

We report results of resistivity measurements at ambient and hydrostatic pressures of up to ≈ 6 kbar. Large resistivity anisotropy sets in below the phase-transition temperature of 0.4 K. In some directions the resistivity increases below 0.4 K, which we interpret as partial gapping of the Fermi surface. Hydrostatic pressure of less than 1 kbar suppresses the low-temperature phase entirely.

The interest in the YbBiPt compound has been sparked by the anomalously large coefficient of the linear in temperature contribution to the heat capacity [1] $\gamma = 8$ J/mol K². If a substantial part of that heat capacity is due to the heavy-fermion nature of the ground state, that value of γ makes YbBiPt the "heaviest" fermion compound known to date. The heat capacity data also revealed a phase transition at 0.4 K as a small peak in the C versus T curve. It is the nature of that transition which is the subject of this paper, together with the clues it may provide to some aspects of the ground state of the system.

The single-crystal samples were grown from excess Bi flux [2]. Standard four-probe AC resistivity measurements were performed in a dilution refrigerator down to 30 mK. Figure 1(a) shows the resistivity data for several rod-shaped samples in which the current flow was close to being parallel to (100) crystallographic direction.

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Below the phase transition temperature of 0.4 K, the resistivity curves no longer fall on top of one another. In fact, both an increase and a decrease in resistivity can be observed for different samples. To ascertain whether the different behavior is a sample-to-sample variation or an inherent property of YbBiPt, we performed resistivity measurements on a single-crystal square platelet in a Montgomery arrangement [3] with long edges close to (100) and (010) directions. By passing excitation current along two perpendicular edges of the sample and detecting voltage along the opposite edge, it is possible to extract resistivities in the directions along the edges. The result of such a measurement and analysis on one of the samples is shown in Fig. 1(b). We see that the resistivity becomes anisotropic, and the cubic symmetry is broken below $T_c = 0.4$ K.

Similar behavior has been observed [4] in Cr, which undergoes a spin density wave (SDW) transition at 311 K. SDW results in gapping of a part of the Fermi surface along the direction of the SDW ordering vector Q , with a corresponding increase in resistivity along the same direction. However, in the case of Cr the anisotropy must be brought out by applying either magnetic field or

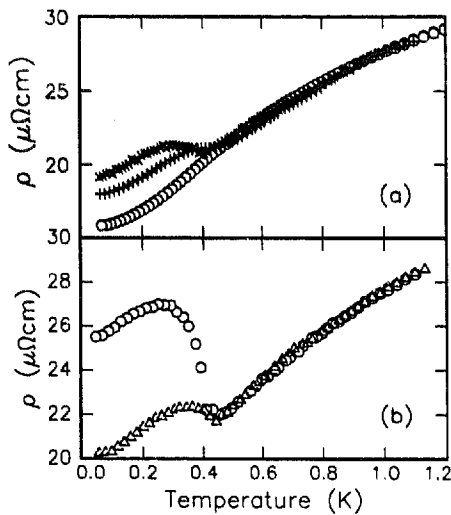


Fig. 1. Resistivity of the YbBiPt: (a) three different rod-shaped samples; (b) Montgomery-type thin platelet sample, with excitation current applied along perpendicular (1 0 0) and (0 1 0) directions.

uniaxial stress to the sample to align randomly oriented (with \mathbf{Q} along three equivalent (1 0 0) directions) domains. The fact that we see anisotropy without changing external parameters (magnetic field or stress) implies that either there are very few large domains in the sample, or the domains are oriented, perhaps by internal stress developed during material growth.

Another possible origin for the transition that we must consider is a superzone gap. In this case the local moments undergo an antiferromagnetic transition with the ordering vector \mathbf{Q} , and the potential resulting from a variation of the magnetic field leads to the Fermi surface instability, with gaps opening up around \mathbf{Q} . Such a situation exists, for example, in the case of some pure rare-earth metals [5]. For some of the metals that undergo an antiferromagnetic transition, such as Dy, Ho, Er and Tm, the resistivity along the c -axis rises, and along the a -axis it decreases [6] in a manner strikingly similar to the data in Fig. 1. In the case of the rare earths, however, the crystal structure is hexagonal, and resistivity anisotropy is present above the ordering temperature as well. For that scenario to apply to YbBiPt, we have to reconcile it with a rather small signature of the transition in the heat capacity data. The size of the anomaly there would necessitate a very small ordered moment on Yb as the sample is cooled below $T_c = 0.4$ K. The small magnetic moment that seems to be necessary is consistent with both μSR [7] and recent elastic neutron scattering experiments [8] that indicate an ordered moment of less than $0.1\mu_B$. This, in turn, points to the importance of local spin compensation and heavy-fermion correlation effects.

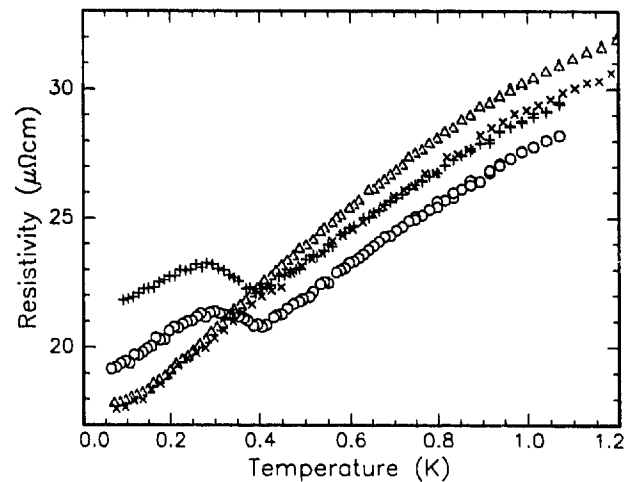


Fig. 2. Resistivity of a single-crystal rod-shaped sample of YbBiPt under hydrostatic pressure: (○) 0 kbar, (+) 0.54 kbar, (×) 0.95 kbar, (Δ) 3.95 kbar. The low-temperature phase is suppressed by pressure between 0.54 and 0.95 kbar.

Figure 2 shows the effect of hydrostatic pressure on the resistivity of YbBiPt. We see that application of a rather small pressure, between 0.56 and 0.95 kbar, suppresses the low-temperature phase entirely. Such high sensitivity to relatively small pressure again points in the direction of a Fermi surface instability, like SDW, where Fermi surface nesting is necessary for the transition to occur. Additionally, YbBiPt seems to be a semimetal, with small hole pockets at E_F [9]. Such band structure may be susceptible to nesting needed for SDW and, perhaps, superzone gap formation. It may also be very sensitive to pressure.

In conclusion, the phase transition at 0.4 K in YbBiPt breaks the cubic symmetry of the crystal. Resistivity becomes highly anisotropic without variation of external parameters, such as applied magnetic field or uniaxial stress. Resistivity rises along some directions of the lattice, indicating that the Fermi surface is gapped. We suggest SDW or superzone gap formation with extremely small ordered local moment to be the most probable nature of that transition. This identification is further supported by extremely high sensitivity of the low-temperature phase to hydrostatic pressure.

Work at Los Alamos was performed under the auspices of the US Department of Energy.

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