Evidence for a Small Hole Pocket in the Fermi Surface of Underdoped $YBa_2Cu_3O_y$

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Introduction

The phase diagram of the cuprates is shaped by ordered states and their identification is essential for understanding high temperature superconductivity. Evidence for a new state in cuprates recently came from two major developments. The observation of quantum oscillations and negative Hall effect in underdoped $YBa_2Cu_3O_y$ (YBCO) [1] showed that the Fermi surface is reconstructed at low temperature, implying a state with broken translational symmetry. More recently, charge-density-wave (CDW) modulations were observed in YBCO first by NMR [2], and then by x-ray diffraction [3]. Fermi-surface reconstruction and CDW modulations are therefore two universal properties of underdoped cuprates, which begs the following question: Is the Fermi surface of YBCO compatible with a reconstruction by the observed CDW order?

Experimental

At the NHMFL, we have measured the Seebeck (S) and Nernst (N) coefficients of YBCO up to 45 T. As seen in Fig. 1a, at T = 2 K both S and N exhibit giant quantum oscillations (QO). At 18 K, these QO are damped, which reveals weaker slow oscillations (Fig. 1b). In Fig. 1c, we see that the oscillations at 18 K are periodic in $1/B$, with a frequency F_b = 95 T. The fast QO at 2 K have a main frequency F_a = 540 T, consistent with prior reports.

Results and Discussion

This slow frequency F_b was subsequently observed in the c-axis resistivity at the LNCMI in Toulouse. It was shown to bear all the key signatures of QO from a small, quasi-2D Fermi pocket: it obeys the Lifshitz-Kosevitch temperature dependence with a light mass of 0.45 m_0, and the field-angle dependence of F_b is close to $1/\cos\theta$ [4]. We therefore ascribe F_b to a hitherto overlooked part of the Fermi surface of YBCO, distinct from the larger electron pocket. To be consistent with the measured Seebeck coefficient in the field-induced normal state of YBCO as a function of doping [5], this Fermi pocket must be hole-like.

Conclusions

Our measurements show that the reconstructed Fermi surface of YBCO includes both electron and hole pockets. Calculations based on the measured CDW in YBCO [6] predict the Fermi surface shown in the inset of Fig. 1b, with one electron and two hole pockets whose sizes are consistent with our measurements. This agreement strongly supports the CDW scenario.

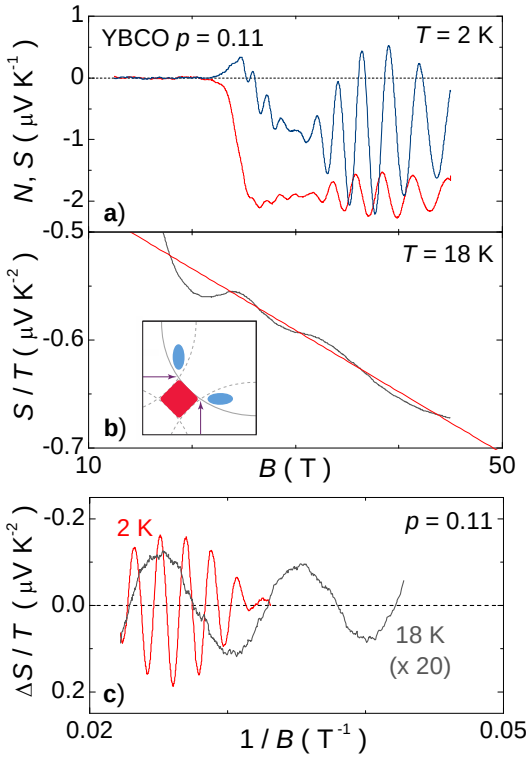

Figure 1: a) Seebeck (S) and Nernst (N) coefficients of YBCO p = 0.11 at 2 K as a function of magnetic field. b) S/T as a function of field at 18 K. Inset: Fermi surface reconstruction by CDW, showing one electron (red) and two hole (blue) pockets. c) Oscillatory part of S/T at 2 and 18 K, versus $1/B$.

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