Magnetotransport in Anisotropic Metals

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Abstract

The in-plane Hall coefficient of the non-superconducting cuprate $Pr_1Ba_2Cu_4O_8$ (Pr124) has been measured in detail over the temperature range 2-300K and shown to have two sign changes. Intriguingly the minimum in the Hall coefficient, R_H, corresponds to a maximum in the zero field resistivity. To compliment other work a comprehensive temperature dependence of the in-chain magnetoresistance has also been carried out on Pr124 with the magnetic field along all three principle crystal axes. This has shown some interesting temperature and field dependence – large and positive for B//a, but smaller and negative for B//b and B//c.

Introduction

Anisotropic materials have electron transport characteristics that are different along different crystallographic directions. Due to their inherent anisotropy (which allows reliable investigation of transport properties along specific crystal axes) quasi-1-dimensional (Q1D) materials are ideal systems in which to study the role of dimensionality on the nature of the electronic ground state in metals.

The ground state of 1D metals is the Luttinger Liquid (LL) which theory predicts is dramatically different from the 3D ground state which is a Fermi Liquid (FL). Experimentalists are searching for departures from FL behaviour. [1, 2]

One of the most anisotropic Q1D metals is $Pr_1Ba_2Cu_4O_8$ (Pr124) which is isostructural with the underdoped 80K superconductor $YBa_2Cu_4O_8$. It consists of alternating planes of 1D double CuO chains (which remain metallic to low temperature) and 2D CuO_2 planes (which are localised due to the hybridization of Pr 4f and O 2p orbitals and therefore not superconducting).

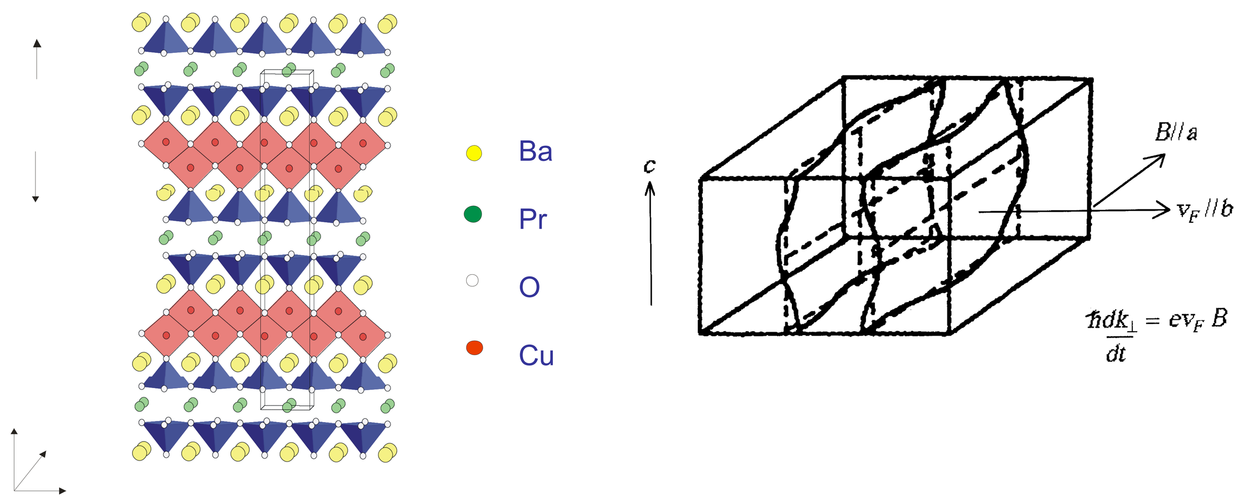

Fig. 1 – Left: Structure of Pr124 showing CuO_2 plane and double CuO chains (a=3.88Å, b=3.9Å, c=13.6Å). Right: Schematic Fermi surface for a Q1D metal.

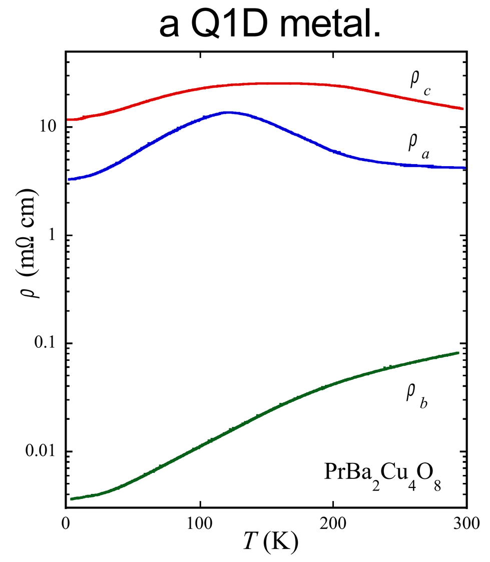

Fig. 2 – Zero Field Resistivity of Pr124 showing extreme anisotropy. [3]

At low temperature transport is metallic and the resistivity has the characteristic T² dependence of a Fermi Liquid in all three directions. As temperature increases both the inter-chain and inter-plane transport become insulating, leaving only the in-chain direction metallic. The resistivity departs from T² in all three directions. [4]

Hall Effect

A single crystal of Pr124 was selected for its long bar-like regular shape. Two current contacts were attached using 6838 sliver epoxy to the a-c face of the crystal. Four voltage contacts were attached on the b-c face (See Fig. 3).

The in-plane Hall effect was measured with current along the chain direction and the magnetic field (12T) along the c axis. The sample was rotated 180° at fixed field and the resistance was measured. Fitting to this allowed values for both the Hall coefficient, R_H, and magnetoresistance to be calculated at a range of temperatures from 2K to 300K. The in-chain mean free path, l_b, was also calculated by the two methods used in Ref. [5].

$$R_H = \frac{E_a}{BJ_b} = \frac{V_H d}{IB} \qquad l_{chain} = \frac{\hbar}{eBa}\sqrt{\frac{\Delta\rho_a}{\rho_a}} \qquad l_{chain} = \frac{ac\pi\hbar}{2e^2}\frac{1}{\rho_b}$$

The Hall coefficient varies significantly with temperature, changing sign about 180K and again at 50K. It is interesting to notice that the minimum of the Hall coefficient corresponds with the maximum in the transverse resistivity.

In a purely 1D structure no Hall effect is expected as carriers can't hop to adjacent chains. A dramatic drop in R_H has been associated with the disruption of transverse charge transport in Nd doped LSCO [6]. It has also been suggested [4] that the peak in ρ_a is due to a gradual crossover from coherent to incoherent inter-chain hopping as temperature increases.

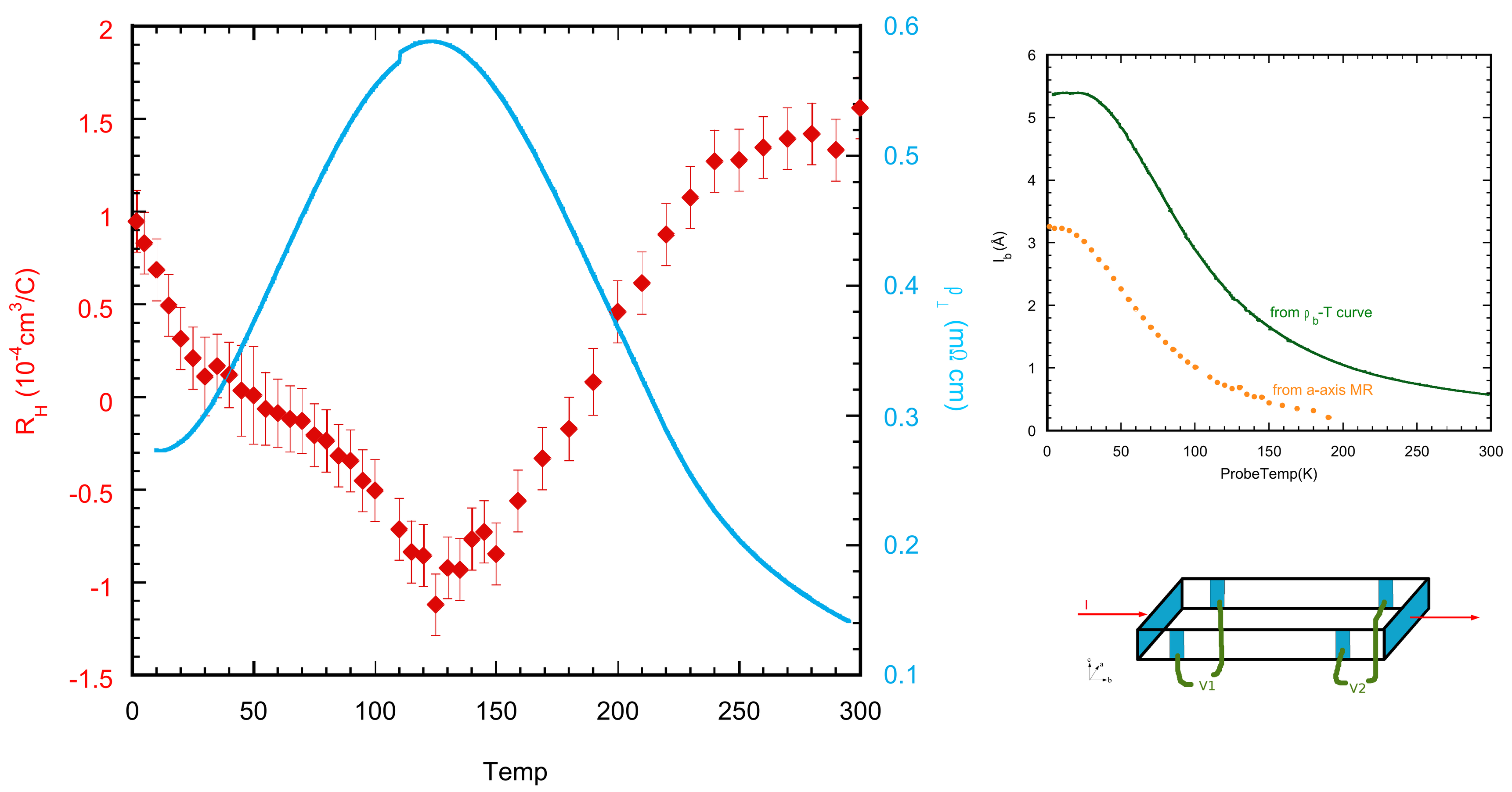

Fig. 3 – Left: Hall coefficient and resistivity measured across the sample (showing characteristics consistent with ρ_a in Figure 2). Top Right: In chain mean free path. Bottom Right: Sample configuration for Hall effect measurements. Sample dimensions were 650μm x 140μm x 6μm

Magnetoresistance

The magnetoresistance (the change in longitudinal resistance when a magnetic field is applied) along the chain (b) direction in Pr124 was measured with the field aligned in turn along the inter-chain (a), in-chain (b) and inter-plane (c) directions. Data was taken between 2K and 200K in fields up to 13.5T.

The magnetoresistance with B//a is large (around 17% at 13T and 2K) and increases monotonically as temperature decreases or field increases. With B//b it is very small (less that 0.5%), since there should be no Lorentz force. For B//c it is still small, but has some field dependent structure at low temperature. From simple consideration of the similarity of the Fermi surface warping (Fig. 1) it could be expected that B//a and B//c would be similar. Clearly this is not the case and is possibly due to different cancellation of Hall coefficients.

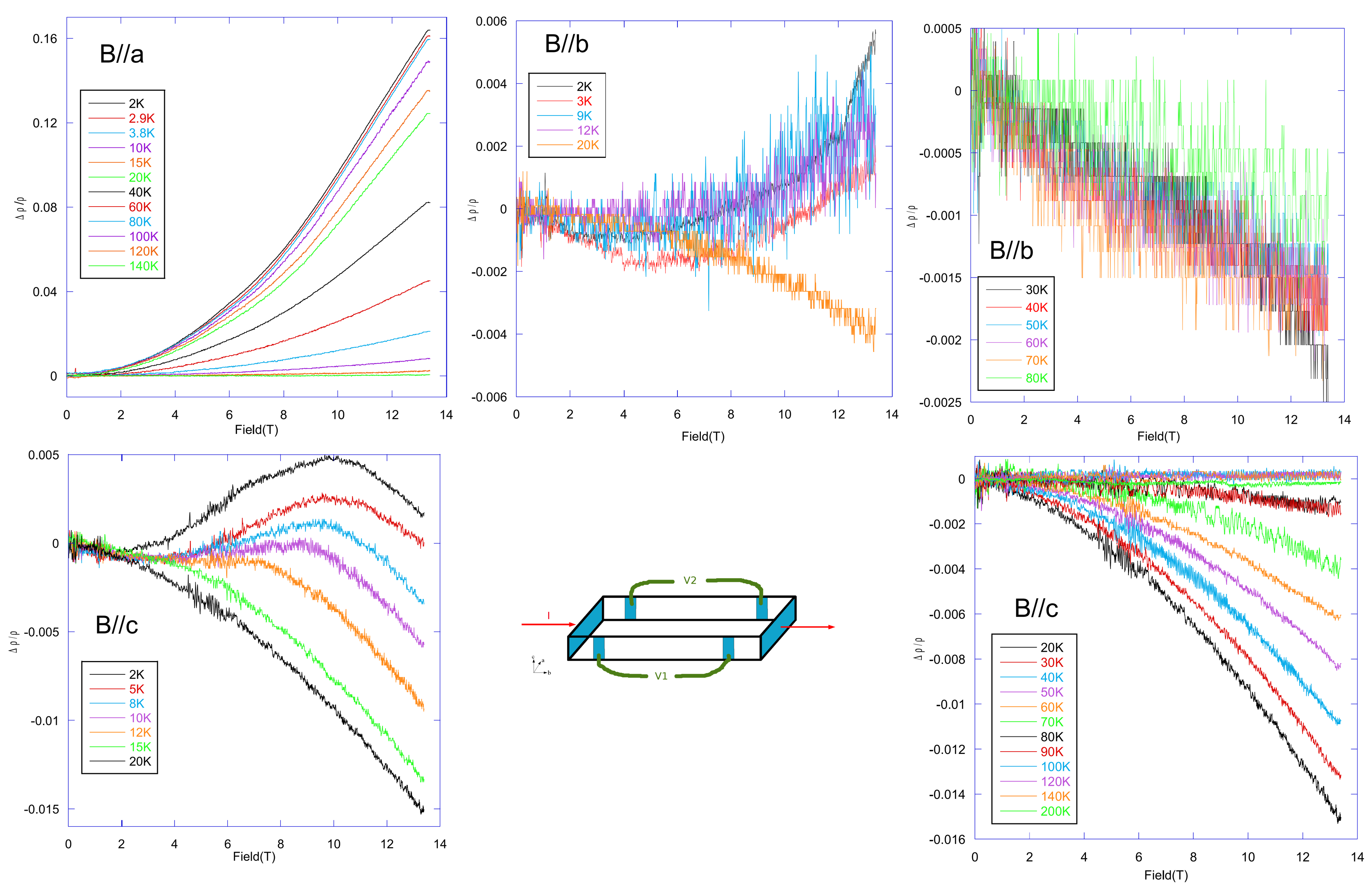

Fig. 4 – Magnetoresistance Graphs with B//a, B//b and B//c and sample configuration.

References

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