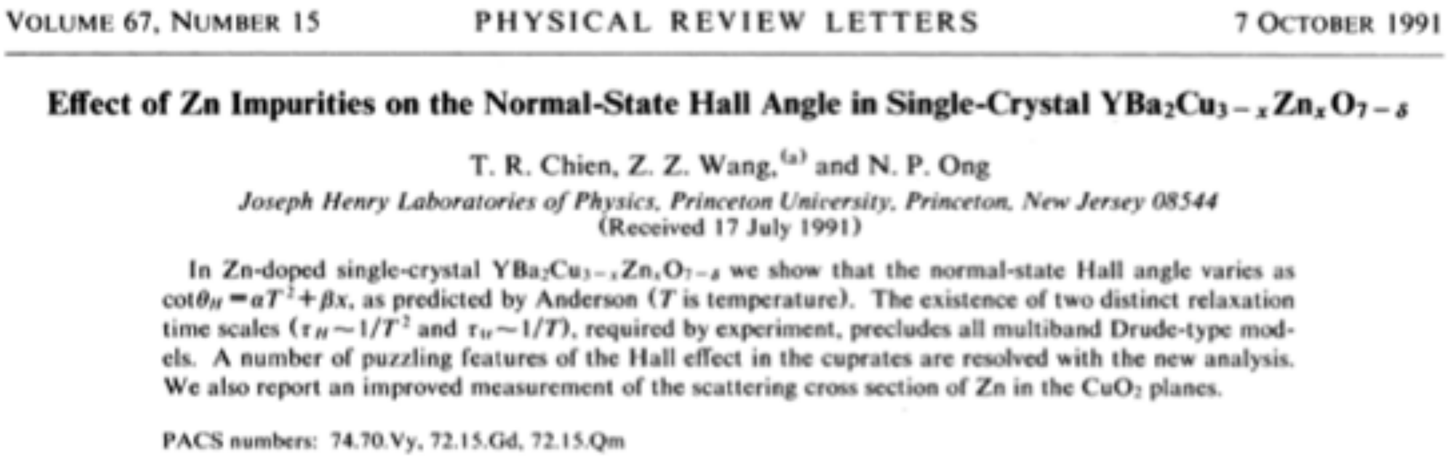
Quantum Critical Transport and the Hall Angle

Mike Blake - DAMTP

arXiv:1406.1659 with Aristomenis Donos

Motivation



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Effect of Zn Impurities on the Normal-State Hall Angle in Single-Crystal $YBa_2Cu_{3-x}Zn_xO_{7-\delta}$

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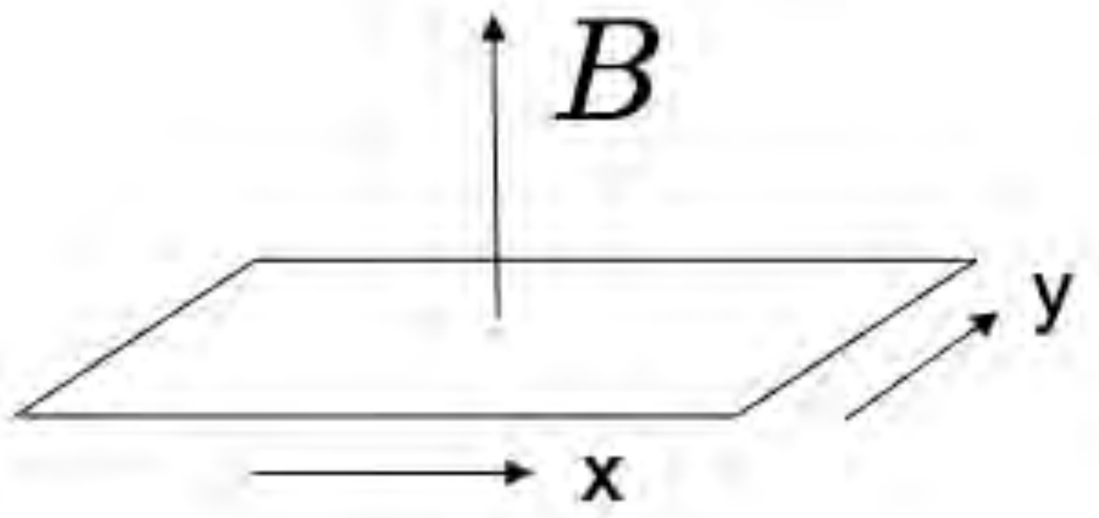
In Zn-doped single-crystal $YBa_2Cu_{3-x}Zn_xO_{7-\delta}$ we show that the normal-state Hall angle varies as $\cot\theta_H = \alpha T^2 + \beta x$, as predicted by Anderson (T is temperature). The existence of two distinct relaxation time scales ($\tau_H \sim 1/T^2$ and $\tau_{tr} \sim 1/T$), required by experiment, precludes all multiband Drude-type models. A number of puzzling features of the Hall effect in the cuprates are resolved with the new analysis. We also report an improved measurement of the scattering cross section of Zn in the CuO_2 planes.

PACS numbers: 74.70.Vy, 72.15.Gd, 72.15.Qm

Could the existence of a quantum critical point explain the anomalous scaling of the Hall angle?

Drude model



$$\vec{j}(\omega) = \sigma(\omega)\vec{E}(\omega)$$

$$m\frac{d\vec{v}}{dt} + \frac{m}{\tau}\vec{v} = q(\vec{E} + \vec{v} \times \vec{B})$$

$$\vec{j} = nq\vec{v}$$

A puzzle...

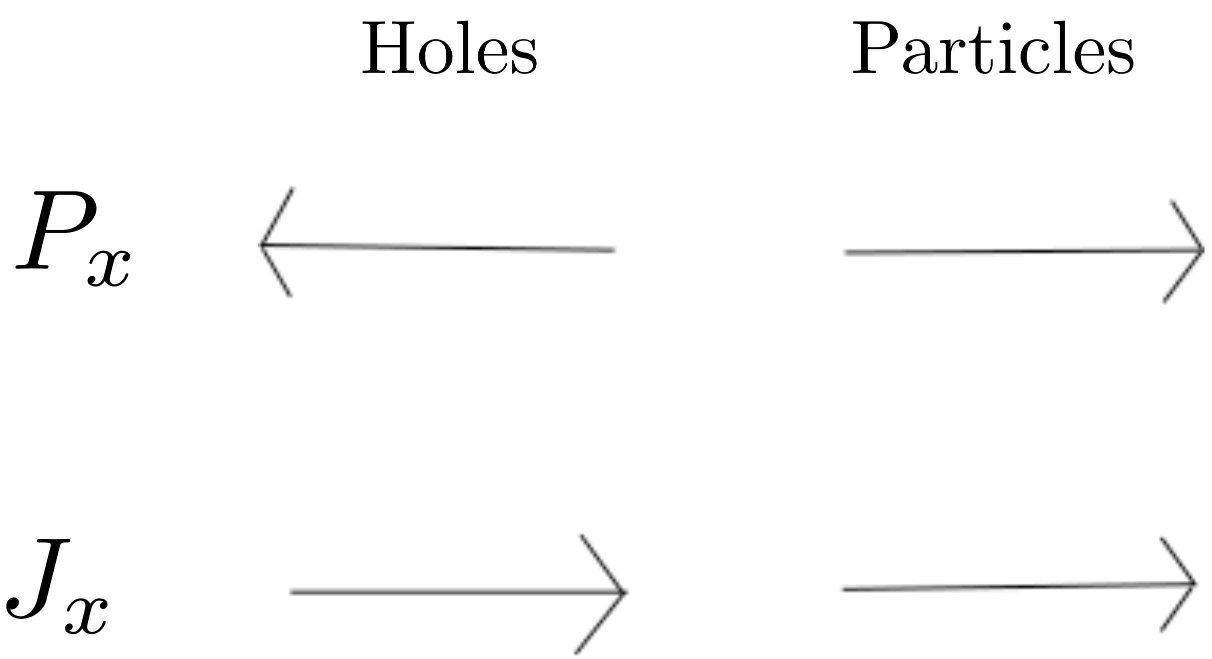
	$B = 0$	$B \neq 0$
Drude	$\sigma_{DC} = \frac{nq^2\tau}{m}$	$\theta_H = \frac{\sigma_{xy}}{\sigma_{xx}} = \frac{qB\tau}{m}$
Strange Metal	$\sigma_{DC} \sim \frac{1}{T}$	$\theta_H \sim \frac{1}{T^2}$

The strange metal experiments seem to imply different scattering times for electric and Hall currents.

Anderson

Coleman, Schofield & Tsvelik

Quantum Critical Transport



Holes Particles

$P_x \quad \longleftarrow \qquad \longrightarrow$

$J_x \quad \longrightarrow \qquad \longrightarrow$

$$\sigma_{QC}(\omega, T) = T^{(d-2)/z}\Sigma(\omega/T)$$

$\omega/T \ll 1:$ Thermally excited

$\omega/T \gg 1:$ Pair produced

Sachdev and Damle

Holographic conductivity

- Huge amount of recent progress in holographic lattice models.
- Exact analytic expressions for transport can be obtained from ‘Q-lattices’.

Donos and Gauntlett

$$S = \int \mathrm{d}^4x\sqrt{-g}\left[R - \frac{1}{2}(\partial\phi)^2 + \Phi(\phi)((\partial\chi_1)^2 + (\partial\chi_2)^2) + V(\phi) - \frac{Z(\phi)}{4}F^2\right]$$

$$\chi_1 \to kx \qquad \chi_2 \to ky$$

DC conductivity

$$\sigma_{DC} = \sigma_{QC} + \frac{\mathcal{Q}^2}{\mathcal{E}+\mathcal{P}}\tau_L$$

$$\sigma_{QC} = Z(\phi)|_{r_+} \qquad \tau_L^{-1} = \frac{s}{4\pi}\frac{k^2\Phi(\phi)}{\mathcal{E}+\mathcal{P}}\bigg|_{r_+}$$

\`Inverse Matthiesen Law’

MB & Tong; MB, Tong & Vegh;
Gouteraux; Andrade &Withers;
Gauntlett & Donos...

Hall angle

$$\theta_H = \frac{BQ}{e^{2V}k^2\Phi}\left[\frac{B^2Z^2 + Q^2 + 2Ze^{2V}k^2\Phi}{B^2Z^2 + Q^2 + Ze^{2V}k^2\Phi}\right]\Bigg|_{r_+}$$

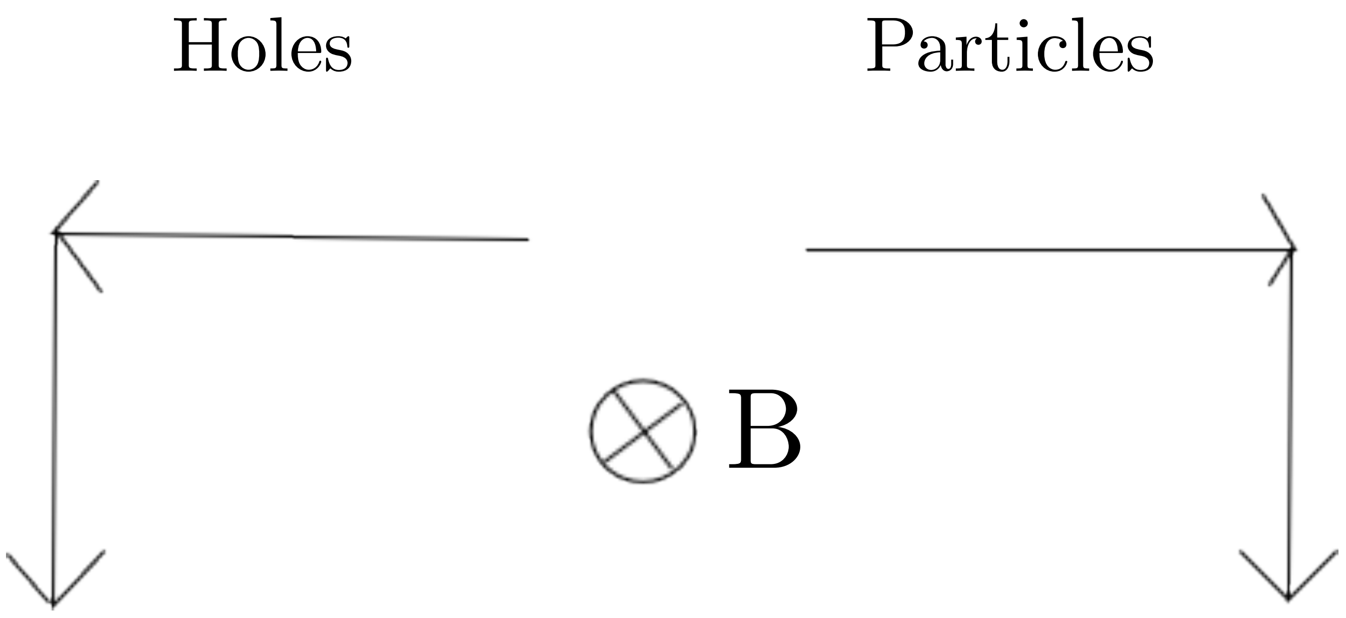
Hall angle

$$\theta_H \sim \frac{BQ}{\mathcal{E} + \mathcal{P}} \tau_L$$

Hall angle

$$\theta_H \sim \frac{BQ}{\mathcal{E}+\mathcal{P}}\tau_L$$

No analogous term to σ_{QC}



MB and Donos

- Weak momentum dissipation - $\tau_L \to \infty$

$$\sigma_{DC} = \frac{\mathcal{Q}^2}{\mathcal{E}+\mathcal{P}}\tau_L \qquad \theta_H = \frac{B\mathcal{Q}}{\mathcal{E}+\mathcal{P}}\tau_L$$

reproduces Drude-like results.

c.f.
Hartnoll &
Hofman etc

- Strong momentum dissipation - $\tau_L \to 0$

$$\sigma_{DC} = \sigma_{QC} \qquad \theta_H = \frac{2B\mathcal{Q}}{\mathcal{E}+\mathcal{P}}\tau_L$$

can now get different scalings!

Comments

- Story can be applied more generally than to the specific lattice models studied here e.g. to hydro, probe branes.

  Karch

- For strong momentum relaxation we expect a dichotomy in transport properties between those σ_{QC} contributes to and those it doesn't.

- Would be exciting to understand whether mechanism can be applied to the cuprates or other experimental systems.

`` Over broad regions of doping, the two kinds of relaxation rates, the one for the conductivity and the one for the Hall rotation, seem to add as inverses: Conductivity is proportional to 1/ T + 1/ T^2—that is, it obeys an anti-Matthiessen law.’’

P.W. Anderson - Physics Today

Thank you!