Probing Quantum Phase Transitions and Domain Dynamics with the Hall Effect

- High-Tc’s: YBCO
- Mott-Hubbard Transition: \( \text{V}_2\text{O}_3 \)
- SDW Order: Cr

Approach to the QCP (Minhyea Lee)
Domain Wall Motion (Rafael Jaramillo)

Hall Effect and YBCO

\[ \sigma_{xx} \sim \tau_r \; ; \; \sigma_{xy} \sim \tau_r \; \tau_H \; ; \; \cot \theta_H = (\sigma_{xx} / \sigma_{xy}) \sim 1/\tau_H \]

CHARGE & SPIN: \( \tau_r \sim 1/T \) vs. \( \tau_H \sim 1/T^2 \)

Hall Effect and $V_2O_3$

More Metallic


$\tau_{tr} \sim 1/T^{3/2}$ (SCR) vs. $\tau_H \sim 1/T^2$
NEAR HALF-FILLING (Mott-Hubbard QCP)

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SDW in CHROMIUM

- Cr is a 3$d$- transition metal with a simple BCC structure.
- The only elemental Antiferromagnet.
- Spin-density wave ground state at 311 K.
- Drive $T_N$ to zero by Doping with $V$
  (effectively increasing the size of the hole pocket)
or by Applying Pressure.

Fermi surface for Cr:
SDW of wave vector $Q$ produces energy gap
(Fawcett, RMP 60, 209 (1994))
Hall Effect and Cr_{1-x}V_x

- Hall Coefficient jumps by a factor of two at the QCP!

Does the Longitudinal Resistivity see the QCP?
Does \( R_H \) really jump?

Temperature dependence of \( \rho_{xx} \) at various \( P \)

- Temperature dependence of resistivity evolves smoothly through the QCP
- \( \rho (T) \sim T^3 \) due to phonons in the paramagnetic phase.
- No non-Fermi liquid signature.
Temperature Dependence of the Hall Coefficient:

- High T Evolution, viz. YBCO
- Sharp decrease in $1/R_H$ as SDW Gap opens
- $T = 0$ Discontinuity?

Pressure Dependence of Inverse Hall Coefficient

At the $T \to 0$ QCP:

Continuous Evolution of
\[ R_H^{-1} \sim (P_c - P)^{0.50 \pm 0.02}, \]

with $P_c = 7.5 \pm 0.1 \text{ kbar}$,

M. Lee et al., PRL 92, 187201 (2004)
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$\Delta \rho/\rho (T)$ as measure of SDW Order Parameter

$\Delta \rho/\rho (T) \sim (P_c - P)^{0.68 \pm 0.03}$ with $P_c = 7.5 \pm 0.1$ kbar.

Final Exponent: Isothermal Cut of $\Delta \rho (T,P)$

- Pressure dependence of $T_N$ can be determined from the fitting results:
  $T_N \sim (P_c - P)^{\alpha}$ with $P_c = 7.5 \pm 0.1$ kbar

- $\Delta \rho(P)$ at all $T$ fits $(P_c - P)^{0.68 \pm 0.03}$ with inhomogeneity $\Delta x = 0.9\%$. 
Domain Structure and Dynamics in Cr

Hall Hysteresis of SDW Domains:

\[ T_N = 311 \text{ K}; \quad T_{SF} = 123 \text{ K} \]

R. Jaramillo et al.

X-ray Microscopy:

S and Q Domains

E. Isaacs et al.

Pinning and Fluctuations

Scratching the surface orients the domains: **Collapse hysteresis**

Different scattering modes: **Hysteretic reversal and noise**
Summary

✓ Hall coefficient reveals relationship between spin & charge in cuprates, heavy fermions and at Mott-Hubbard transition in $V_2O_3$.

✓ Hall coefficient is the most sensitive probe of the QCP in $Cr_{1-x}V_x$:
  ** Factor of two change with $1/R_H \sim (P_c-P)^{0.50\pm0.02}$
  ** Strong temperature dependence above $T_N$

✓ Hall coefficient remarkably sensitive to microscopic structure and dynamics of SDW domains (cf. CMR materials?).

$R_H$ a POWERFUL and UNDERUSED TOOL

Universal Relation of $T_N (P, x)$ Obtained from Different Experiments on CrV alloy: Disorder Not Dominant

- Arajs et al., 1969; Resistivity
- White et al., 1986; Thermal expansion
- Komura et al., 1967; Neutron Diffraction
- Barnes and Graham. 1965 ; NMR
- Trego and Mackintosh, 1968: Resistivity
- Yeh et al., 2002 ; Resistivity
- Pure Cr by McWhan, 1968 : Resistivity
- V 2.8% by Rice et al., 1969 ; Resistivity
- V 1.2% by Rice et al., 1969 ; Resistivity
- V 3.2% by Lee et al., 2004 ; Resistivity