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Magneto-transport and Glassiness at Nanoscale Coexistence

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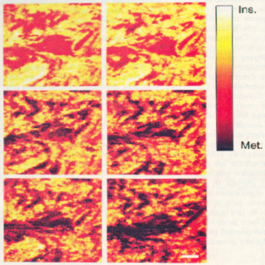
Nano-05, MPIPKS Dresden

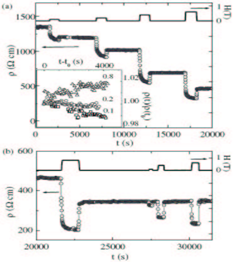
Outline

1. Motivation
   - Phase Separated Manganites: Experiments
   - Theory Efforts
2. Model and Method
   - Competing Interactions and Disorder
   - Self Consistent Renormalisation(SCR)
3. Results
   - Magneto-transport
   - Glassiness

Inhomogeneities and Slow Relaxation



Fath *et al.* (1999)



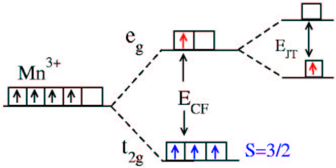
Levy *et al.*(2002)

- Glassiness in $Pr_{0.7}Ca_{0.3}MnO_3$. Deac *et al.* (2001)

Understanding the Phase Coexistence Regime

- Difficulty: Inhomogeneous structure.
- Real space monte-carlo methods.
  Moreo *et al.* (2000)
- Resistor network theory for studying transport.
  Mayr *et al.* (2000)
- Very few theory efforts to understand the slow relaxation, glassiness or history dependence.

Double Exchange vs. Superexchange



Our focus is on phase competition:

$$H = -t \sum_{\langle ij \rangle, \sigma} (c^{\dagger}_{i\sigma} c_{j\sigma} + h.c.) + \sum_i (\epsilon_i - \mu) n_i - J_H \sum_i \mathbf{S_i} \cdot \sigma_{\mathbf{i}} + J_S \sum_{\langle ij \rangle} \mathbf{S_i} \cdot \mathbf{S_j}$$

J_S: AF coupling , Δ: disorder, n: electronic density

The Double Exchange Limit

$J_H \rightarrow \infty \quad \Rightarrow \quad c_i \rightarrow \gamma_i$

Electronic spin slaved on to the core spin.

$$\begin{aligned} H_{el} &= -t \sum_{\langle ij \rangle} (g_{ij} \gamma_i^\dagger \gamma_j + h.c) + \sum_i (\epsilon_i - \mu) n_i \\ &= -t \sum_{\langle ij \rangle} \sqrt{(1 + \mathbf{S}_i.\mathbf{S}_j)/2} (e^{i\Phi_{ij}} \gamma_i^\dagger \gamma_j + h.c) + \sum_i (\epsilon_i - \mu) n_i \end{aligned}$$

$$g_{ij} = \cos(\theta_i/2)\cos(\theta_j/2) + \sin(\theta_i/2)\sin(\theta_j/2) e^{\iota(\phi_i - \phi_j)}$$

Effective Hamiltonian and EDMC

The Partition Function

$$Z = \int \mathcal{D}\mathbf{S}\ Tr\ e^{-\beta H(\{\mathbf{S}\})} \equiv \int \mathcal{D}\mathbf{S}\ e^{-\beta H_{eff}(\{\mathbf{S}\})}$$

$$H_{eff}(\{\mathbf{S}\}) = -\frac{1}{\beta} log\ Tr\ e^{-\beta H(\{\mathbf{S}\})}$$

$Tr\ e^{-\beta H(\{\mathbf{S}\})}$ can not be calculated analytically for arbitrary $\{\mathbf{S}\}$

- Use Exact Diagonalisation to compute the trace. $\Rightarrow$ EDMC
- EDMC is computation intensive. $N \sim 100$

Self Consistent Renormalisation

- The electronic part of the Hamiltonian:

$$H_{el} = -t\sum_{\langle ij\rangle}\sqrt{(1+\mathbf{S}_i.\mathbf{S}_j)/2}\;(e^{i\Phi_{ij}}\gamma_i^{\dagger}\gamma_j + h.c) + \sum_i(\epsilon_i - \mu)n_i$$

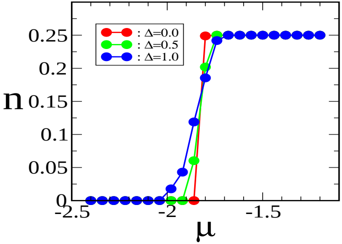
- The effective spin Hamiltonian:

$$H_{eff}(\{\mathbf{S}\}) \approx -t\sum_{\langle ij\rangle} D_{ij}\sqrt{(1+\mathbf{S}_i.\mathbf{S}_j)/2} \;+\; J_s\sum_{\langle ij\rangle}\mathbf{S}_i.\mathbf{S}_j$$

- Parameters for the effective spin Hamiltonian:

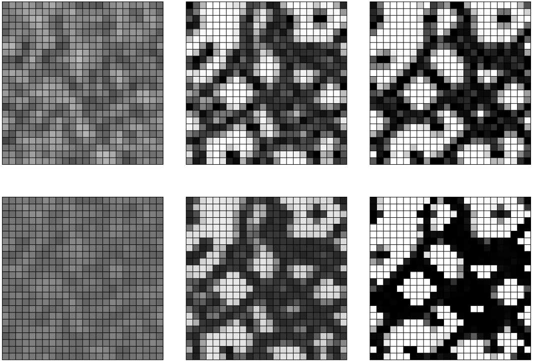
$$D_{ij} = \int \mathcal{D}\mathbf{S}\;\; e^{-\beta H_{eff}(\{S\})}\;\langle(e^{i\Phi_{ij}}\gamma_i^{\dagger}\gamma_j + h.c)\rangle$$

Effect of Disorder on Phase Separation



- 1st order transition from $n = 0$ AF-I to $n \sim 0.2$ FM-Metal.
- Disorder smooths out the $n - \mu$ discontinuity.

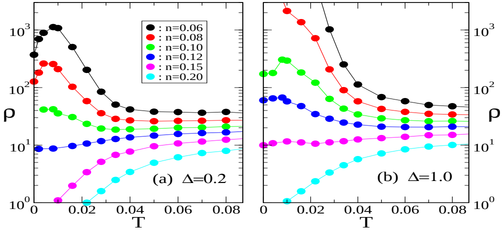
Coexisting FM-M and AF-I Clusters



- $\langle n_i \rangle$ (top row) and $\langle \mathbf{S}_i \cdot \mathbf{S}_{i+\delta} \rangle$ (bottom row) on cooling.

Transport in the Coexistence Regime

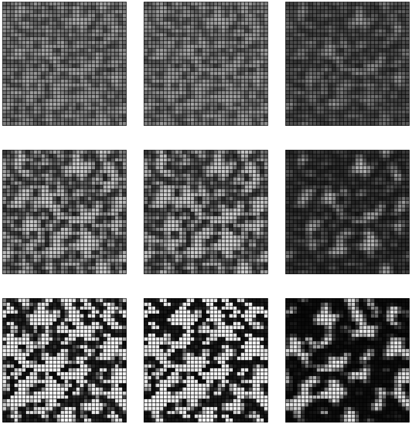
- Resistivity using Kubo formula (*cond-mat / 0504656*)



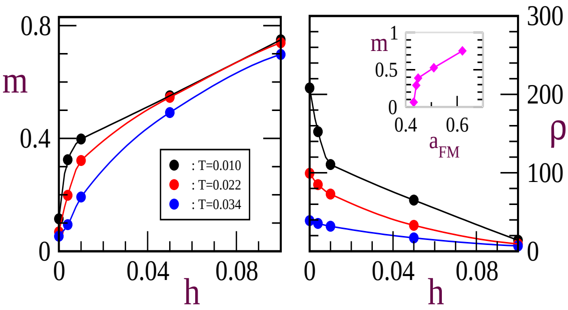
- Density driven MIT. Percolation?
- Hint for a thermally driven MIT.

Effect of External Magnetic Field

Including external magnetic field: $H' = H - h \sum_i \mathbf{S}_i^z$



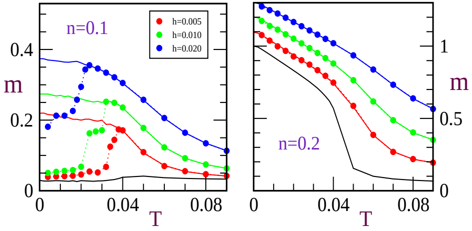
Magnetization and Resistivity: response to h



- Low fields: Alignment of *cluster* magnetic moments
- High fields: Expansion of FM regions.

Field Cooling and Zero Field Cooling

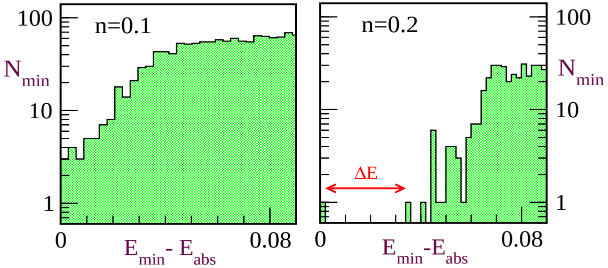
- No Spin-Glass behaviour for O(3) spin model in 2d.
- Weak local anisotropy to lift the $O(3)$ symmetry.



- FC magnetisation differs from ZFC for $n = 0.1$ at low fields.

Density of Local Minima

- Minimize $E(\{\mathbf{S}\})$ using Conjugate-Gradient Method.



- $n = 0.1$: High density of local minima near $E = E_{abs}$.
- $n = 0.2$: Gap at low energy.

Summary

- Transport beyond the simple percolation scenario.
- Low field response: alignment of FM clusters.
- Spin glass behaviour and non-trivial energy landscape.

Outlook:

- 2-band model with JT coupling.
- Structural glass $\Leftrightarrow$ spin glass.

Collaborators:
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Ref. :- Phys. Rev. Lett. **92**, 126602 (2004) ; cond-mat 0503735