Collapse of Electron-Lattice Polarons in Colossal Magnetoresistive Manganites

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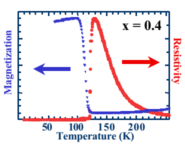
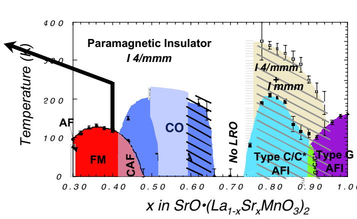
Motivation

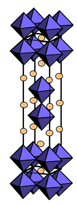
What is the origin of colossal magnetoresistance (CMR) in the manganites? CMR is observed in manganites that simultaneously undergo ferromagnetic and metal-insulator transitions. Near T_c, this transition from paramagnetic insulator to ferromagnetic metal can be driven by an applied magnetic field. Over the last decade, magnetoresistive read-heads have revolutionized the magnetic hard drive industry, and the ability to understand and manipulate the CMR effect could soon bring it to the technological forefront.



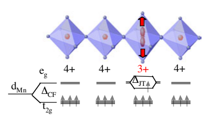
Magnetization & resistivity vs. temperature at x = 0.4.

Phase diagram of $La_{2-2x}Sr_{1+2x}Mn_2O_7$ bilayered perovskites



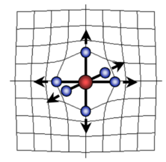


CMR is believed to originate from a strong electron-phonon coupling via the Jahn-Teller (JT) mechanism, which leads to the self-trapping of charge carriers within local lattice distortions. Polarons are charge carriers that carry such a distortion as they traverse the lattice.

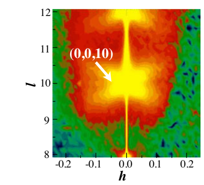


Local JT distortion induced by an extra e_g electron on a Mn^{3+} site.

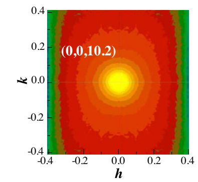
Polaronic strain-field scattering



A local lattice distortion induces a longer ranged strain-field.

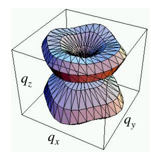


36 keV x-ray single-crystal diffuse scattering data around the (0,0,10) Bragg reflection.

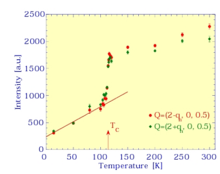


(*h*,*k*,10.2) section of the same scattering distribution.

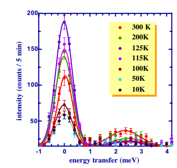
Our synchrotron X-ray and neutron single-crystal diffuse scattering measurements conclusively demonstrate the existence of quasistatic JT polarons in the CMR manganites. The strain-fields that emanate from polaronic JT distortions produce highly-anisotropic Huang scattering distributions around the Bragg reflections.



3D shape of the diffuse scattering

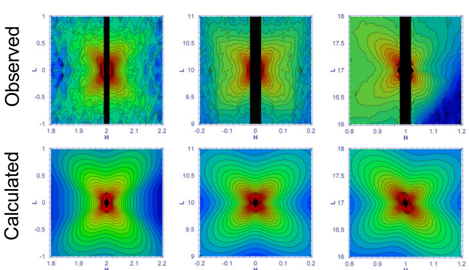


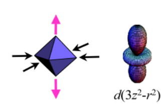
Temperature dependence of the diffuse scattering.



Energy dependence of the diffuse scattering.

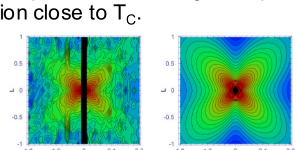
Orbital Polarization

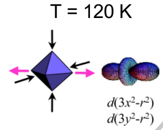




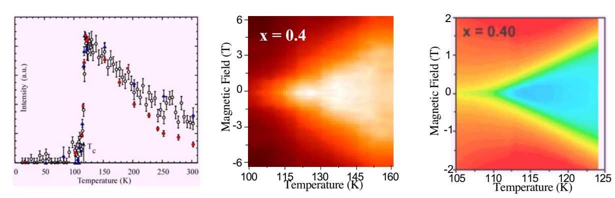
Observed and calculated "butterflies" for T=300K (left) and T=120K (below)

The detailed analysis of the shape of the scattering reveals the presence of orbital polarization. We also observe a change from a mainly out-of-plane polarization at high temperatures to a mainly in-plane polarization close to T_C.





Polaron collapse at T_c



Left: The polarons disappear abruptly at Tc. Middle: diffuse scattering intensity vs. H and T. Right: Effective magnetic J-coupling strength vs. H and T determined from magnetization data.

The polarons disappear abruptly at T_C, both as a function of temperature and applied magnetic field, releasing the electron from their traps. When polaronic structure is evident, the ferromagnetic response is weak, as though the J-coupling strength is anomalously small. The polarons, which inhibit the motion of the charge carriers, are destabilized under the influence of ferromagnetic order, and their collapse greatly accentuates the resistivity changes at T_c. We conclude that this combination of polaron formation and destabilization is the essence of CMR.

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This work was supported by the U. S. Department of Energy, Basic Energy Sciences, under contract W-31-109-ENG-38. Work at NIST was supported in part by the Binational Science Foundation, Grant No. 2000073.

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