Chapter 1. Mesoscopic Quantum Magnetic Conductors

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1.1 Order Driven by Disorder

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Over the past several years, a new class of novel mesoscopic materials characterized by "intermediate" dimensionality has been discovered. These derive from materials research in the field of high-temperature superconductivity. However, the physics issues, including especially the magnetic and electronic properties of these "intermediate" dimensional materials, are quite distinct from those of the "two-dimensional" high-temperature superconductors. Specifically, a variety of new materials have been discovered which are composed of either isolated or coupled copper oxide chains. The behavior of these systems as a function of n, the number of coupled chains, is quite remarkable. Coupled chain systems in which one of the constituents in the rows is magnetic (e.g., Cu^{2+}) are referred to as "spin ladders." By varying the chemistry, one can dope these "spin ladders," producing novel quantum magnetic conductors.

Ladders with an odd number of chains have gapless spin excitations and, on doping, should behave like Luttinger liquids. Even chain ladders, on the other hand, have a gap in their spin excitation spectrum and, therefore, on doping could exhibit fundamentally different behavior. Replacing the Cu^{2+} atoms which have S = 1/2, for example, by Zn^{2+}, which has S = 0, will cause the spin chain to break into finite size segments. Length scales from nanometers to microns can easily be achieved in this fashion. Recently, Azuma and coworkers discovered that in the n = 2 spin ladder material, $SrCu_20_3$, doping with Zn, that is, synthesizing $Sr(Cu_{1-x}Sn_x)_2O_3$, causes the system to exhibit long-range antiferromagnetic order. In other words, disordering the Cu^{2+}(S=1/2) ladders by adding Zn^{2+} (S =0) causes the material to change from a one-dimensional short ranged ordered state to three dimensional long-range order. This is counter-intuitive since one might think that putting in disorder via the Zn^{2+} would cause the spin system to become even more disordered. It turns out that this phenomenon derives from a pure quantum mechancial effect occuring in one-dimensional spin systems. Using quantum Monte Carlo techniques, we have elucidated the mechanisms by which the spinless Zn^{2+} dopants cause the order to grow within the one-dimensional spin ladders. By careful consideration of the actual structure of $SrCu_20_3$, we deduce that there should be successive crossovers of the ladder spin ordering from one to two and ultimately to three dimensions. This model will be testable by neutron scattering techniques once suitably large crystals have been grown.

1.1.1 Publication

Greven M., and R.J. Birgeneau. "Correlations and Neel Order of Randomly Diluted Quantum Spin Ladders." Submitted to *Phys. Rev. Lett.*