Low Dimensional Quantum Magnetism in the Copper Oxides

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The magnetism of lamellar copper oxides, which are the parent materials of high temperature superconductors, is dominated by the spin 1/2 Cu^{+2} ions on the CuO_2 planes. These planes have Cu ions on the vertices and O ions on the bonds of a square lattice, and their magnetic behavior at high temperature is described well by the planar quantum Heisenberg antiferromagnetic (AFM) model, which has long range order only at T=0. In fact they have three dimensional AFM order due to weak spin anisotropies and interplane couplings. Starting from a Hubbard model with spin orbit and Coulomb exchange couplings, we derive an effective magnetic Hamiltonian which contains these anisotropies and couplings. An analysis of the zero point quantum spin wave energies generates additional four-fold symmetry terms and delicate higher order interplane interactions, which help select a ground state among states which would otherwise be degenerate due to frustration. Having generated the full effective magnetic Hamiltonian, the results are used to identify the magnetic structures and competitions among them, leading to phase diagrams in parameter space. These are also used to discuss the critical phenomena which occur near various possible transitions. Specific attention will be devoted to the structures of tetragonal $Sr_2CuO_2Cl_2$, Nd_2CuO_4 and Pr_2CuO_4. In the former, frustration among layers is lifted by pseudodipolar interactions and by quantum zero point energies. In the latter two, the rare earth also participates in the magnetism. We shall then discuss orthorhombic La_2CuO_4, where the Dzyaloshinskii-Moriya antisymmetric anisotropic interactions exhibit an interesting hidden symmetry.

Finally, we shall give full analysis of $Sr_2Cu_3O_4Cl_2$, which contains Cu_3O_4 planes with an extra Cu ion in the center of every second Cu plaquette. Each of the two types of Cu ions reaches AFM order separately, and the system also exhibits an interesting ferromagnetic moment. A theory in which the intersublattice coupling is described by pseudodipolar interactions allows us to deduce various coupling constants. Similarities in the relative Cu-O-Cu geometries enable us to relate these coupling constants to the nearest and next nearest neighbor interactions in many chain, ladder and lamellar cuprates. These have consequences concerning the magnetic behavior of the latter systems: competing nearest and next nearest neighbor couplings explain the spin gap observed in the chains, and the new pseudodipolar interactions remove frustration in the interladder coupling. If time allows, we shall also discuss the effects of doping on some of these systems. Doping sometimes gives rise to a spin glass state, and sometimes enhances the AFM correlations and reduces the effective magnetic gaps.