

Loss of Neel order in doped antiferromagnets

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We describe the loss of Neel order on $S=1/2$ square lattice antiferromagnets by electron doping. We begin with a state with co-existing Neel order and d-wave superconductivity (AFM+SC). We find that there are three distinct transitions by which Neel order can be lost, which are similar to those found in insulating antiferromagnets for different spin S . Thus a doped $S=1/2$ antiferromagnet behaves in some respects like an insulating antiferromagnet with a variable S . This happens because the Berry phases of the monopoles can be partially or completely compensated by the Berry phases of vortices in the Cooper pair condensate. The distinct possibilities for the Berry phases constitute a kind of “topological order” in the AFM+SC state. The three transitions to a d-wave superconductor without Neel order are: (i) an $O(3)$ transition to a generic superconductor, similar to spin density wave theory, (ii) a “doubled monopole” transition to a nematic superconductor, and (iii) a CP^1 transition to a valence bond supersolid. We also consider the loss of Neel order in metallic states, and find a $O(4)$ transition to a fractionalized “doublon/holon metal” state.