Quantum criticality beyond the Landau-Ginsburg-Wilson paradigm

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The authors present persuasive arguments that there should exist a class of zero-temperature quantum phase transitions, in systems with two space dimensions , which have no direct classical counterparts, and which have some quite surprising properties. An important example is the transition between the antiferromagnetic (AF) state and the valence-band solid (VBS) phase of a spin-1/2 Heisenberg model on a square lattice . Another example, where the evidence is in fact stronger, is the transition between an AF state and a VBS-like state in a spin model with easy plane anisotropy. The VBS phases have broken translational symmetry, but no broken symmetry in spin space, as spins form singlet pairs on one quarter of the nearest neighbor bonds. By contrast, all bonds are equivalent in the AF phase, though there is a difference between sites on the two sublattices, and there is a broken symmetry in spin space.

According to the Landau-Ginzburg-Wilson classification, which works well for classical phase transitions in three or more dimensions, and which might normally be expected to work for quantum phase transitions in two dimensions, any direct transition between two phases of these symmetries should be first order (except for special cases involving precise adjustment of one or more additional parameters). The authors argue, however, that a critical point transition is in fact possible in this case, and that the ground state at the critical point should be peculiar in a number of ways. The critical state has a symmetry that is higher than the states on both sides; and the exponents for spin correlations at the critical point do not correspond to those of a classical physical model in three space dimensions (rather the exponents correspond to a peculiar spin model with hedgehog configurations suppressed). Moreover, at the critical point , there exist finite-energy unconfined excitations with fractional quantum numbers, which do not exist as unbound excitations in either the AF or VBS states.

Although the authors cannot rigorously rule out the possibility that some additional phases, or a first order transition, might occur between the AF and VBS states for any given microscopic Hamiltonian, they present evidence from renormalization group arguments, from analogies with other systems, and from prior numerical work, to support the thesis that their peculiar critical points will occur for some range of Hamiltonian systems. It is an open question whether this critical point can be realized in an experimentally accessible physical system, but the theory is in any case interesting, as it significantly extends our appreciation for the kinds of transitions that can occur in principle. We are, by now, accustomed to critical points that deviate from the Landau-Ginzburg-Wilson paradigm for classical models in two dimensions, (such as the three-state Potts model, which should have a first order transition according to the Landau criterion but has a critical point in d=2), and we have one-dimensional quantum examples, such as the spin-1/2 Heisenberg antiferromagnetic chain, where spin systems can be very different from their classical counterparts in one higher dimension. But the proposed behavior in a zero-temperature quantum system with two space dimensions is something new. The authors hope that a generalization of their paradigm may help to explain anomalous behavior in existing systems, such as at the onset of magnetic order in some heavy fermion metals.