Phase transition in fluctuations of interacting spins at infinite temperature

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The high temperature limit of interacting spins is usually not associated with ordering or critical phenomena. Nevertheless, spontaneous fluctuations of a local spin polarization at equilibrium have nontrivial dynamics even in this limit. Here, we demonstrate that the spin noise power spectrum of these fluctuations can undergo discontinuous changes as a function of an external magnetic field. As a simple illustration, we consider a model of Ising-like long range spin-spin interactions with a transverse magnetic field as a control parameter. This system undergoes a phase transition associated with disappearance of the noise power peak responsible for the most detrimental decoherence effect of the interactions.

This work was inspired by a rapid progress with synthesis of novel Metal–Organic Frameworks (MOFs) -- the organic materials that incorporate metallic ions with uncompensated spins in a regular array. The atomic spins can be placed at a sufficient distance from each other to remove exchange interactions. Thus, the spins form a macroscopic array of qubits with considerable coherence time at cryogenic temperatures. MOFs should then provide a platform for experiments with quantum many-body physics at macroscopic scale. However, such large qubit systems induce collective decoherence effects that are absent on the level of a single qubit.

A lot about the effects of decoherence in MOFs can be inferred from the prior studies of molecular nanomagnets . The latter are molecules whose magnetic ions form relatively large net spins, which can also form regular magnetic arrays. At cryogenic temperatures the phonon-related mechanisms of decoherence in molecular magnets are generally suppressed but coherent spin dynamics is not observed due to random hyperfine, of order of a few tens of Gauss, and magnetic dipole fields from neighboring spins (a few hundred of Gauss).

The hyperfine effects can be suppressed substantially by isotopic purification, but the random long-range dipole fields in the sample represent a considerable problem for quantum control. Unlike the molecules with large spins, MOF qubits with spins-1/2 do not experience the quadratic crystal anisotropy. Hence, an external magnetic field that strongly exceeds the typical dipole fields induces coherent precession of all spins around the field axis. However, it is not convenient to use strong fields in practice.

In this work, we explore both numerically and analytically the coherent behavior of long-range interacting spins in a moderate external magnetic field. The most unfortunate effect of the dipole spin-spin interactions is the relatively slow collective relaxation of the local spontaneous spin field fluctuations. The latter mis-allign the net effective fields that act on different spins from the external field axis. Therefore, there is no possibility to define a single rotation axis for the spins in the lattice.

The main finding of our theory is that this most detrimental decoherence effect disappears at relatively week, of an order of the typical dipole field fluctuation, value of the external field. For a stronger field, the spin-spin interactions still contribute to the lifetime but they no longer mis-allign the spin precession from around the direction of the external field.