Decoherence of a qubit interacting with a complex spin bath

Nanako Shitara
Department of Chemistry, University of Colorado Boulder, Colorado 80309, USA and
Department of Physics, University of Colorado Boulder, Colorado 80309, USA

Andrés Montoya-Castillo*
Department of Chemistry, University of Colorado Boulder, Colorado 80309, USA

An open quantum system featuring a spin interacting with spin bath represents one of the most physically ubiquitous models in which a non-Gaussian noise processes emerge. This model offers a physically transparent tool to understand and control decoherence and dissipation in color centers in semiconductors, quantum dot ensembles, and qubit cross talk in quantum information processors. Despite the wealth of analytical and numerical methods developed to predict the dynamics of a system subject to such a bath [1–5], evaluating dynamics of general observables under common measurement and control protocols remains challenging, especially in the presence of complex intra-bath interactions. We propose a novel perturbative framework for predicting the dynamics of a spin system subject to an interacting spin bath. Motivated by the weak intra-bath interactions in relevant platforms, such as nitrogen vacancies centers in diamond, we treat these interactions as the perturbation. We evaluate the dynamics of the coherence measurement across parameter regimes for which the perturbative treatment remains valid, and within these regimes, identify the effects of including intra-bath interactions in the dynamics of observables. Our results provide insight into the validity of approaches neglecting intra-bath interactions in evaluating dynamics employed in many analyses of experimental results.

---

[1] Khaetskii, A.,Loss, D. & Glazman, L. Electron spin evolution induced by interaction with nuclei in a quantum dot. *Phys. Rev. B* **67**, 195329 (2003).
[2] Uhrig, G. S. Keeping a Quantum Bit Alive by Optimized π-Pulse Sequences. *Phys. Rev. Lett.* **98**, 100504 (2007).
[3] Witzel, W. M., de Sousa, R. & Sarma, S. D. Quantum theory of spectral-diffusion-induced electron spin decoherence. *Phys. Rev. B* **72**, 161306(R) (2005).
[4] Saikin, S. K., Yao, W. & Sham, L. J. Single-electron spin decoherence by nuclear spin bath: Linked-cluster expansion approach. *Phys. Rev. B* **75**, 125314 (2007).
[5] Yang, W., Liu, R.-B. Quantum many-body theory of qubit decoherence in a finite-size spin bath. *Phys. Rev. B* **78**, 085315 (2008).

---

* Andres.MontoyaCastillo@colorado.edu