

Many-Body Theory of Phonon-induced Spin Relaxation and Decoherence

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Developing a microscopic understanding of spin relaxation and precession is essential to advancing quantum technologies. Electron spin relaxation due to atomic vibrations (phonons) plays a special role as it sets an intrinsic limit to the performance of spin-based quantum devices. However, a quantitative analysis of spin relaxation remains an open challenge. Two main sources of phonon-induced spin relaxation, the Elliott-Yafet and Dyakonov-Perel mechanisms, have distinct physical origins and theoretical treatments.

In this talk, I will present a many-body framework that unifies their modeling and enables accurate predictions of spin relaxation and precession in materials. I will first show a first-principles workflow that can capture the interactions between electrons and phonons in the presence of spin-orbit coupling [1]. This scheme will be combined with a many-body approach based on the spin-spin correlation function including vertex corrections from electron-phonon interactions [2], allowing accurate predictions of spin relaxation in materials including key semiconductors for quantum technologies (Diamond, Si, GaAs, and WSe₂). These calculations show that the vertex correction provides a giant renormalization of the electron spin dynamics in solids, greater by many orders of magnitude than the corresponding correction from photons in vacuum [3]. In summary, I will demonstrate a general approach for quantitative analysis of spin relaxation and precession in materials, advancing the quest for spin-based quantum technologies.

[1] J. Park, J.-J. Zhou, M. Bernardi, Phys. Rev. B **101**, 045202 (2020)

[2] J. Park, Y. Luo, J.-J. Zhou, and M. Bernardi, Phys. Rev. B **106**, 174404 (2022)

[3] J. Park, J.-J. Zhou, Y. Luo, and M. Bernardi, Phys. Rev. Lett. **129**, 197201 (2022)