Quantum optics with noble-gas spins

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The nuclear spins of noble gases are isolated from the environment extremely well and can maintain coherence for hours. Unfortunately, these spins are not accessible to light in the optical domain. Therefore, as opposed to optically-accessible alkali-metal spins employed in quantum optics and metrology, the (potential) quantum qualities of noble-gas spins have been beyond reach and largely ignored. We show that thermal spin-exchange collisions between noble-gas and alkali-metal spins form a quantum interface between them [1,2]. Despite their stochastic nature, these weak collisions accumulate to a deterministic, efficient, and controllable coupling between the collective spins of the two ensembles. The interface paves the way to employing noble-gas spins in the quantum domain, for example as an optical quantum memory with hour-long lifetimes [3,4]. In experiments, we realize the strong coupling of potassium to helium-3 spins and witness their periodic exchange of spin coherence [5]. We then introduce light fields and demonstrate the efficient optical interface to helium-3 [6]. We discuss the prospects for generating long-lived entanglement between distant noble-gas ensembles [7].

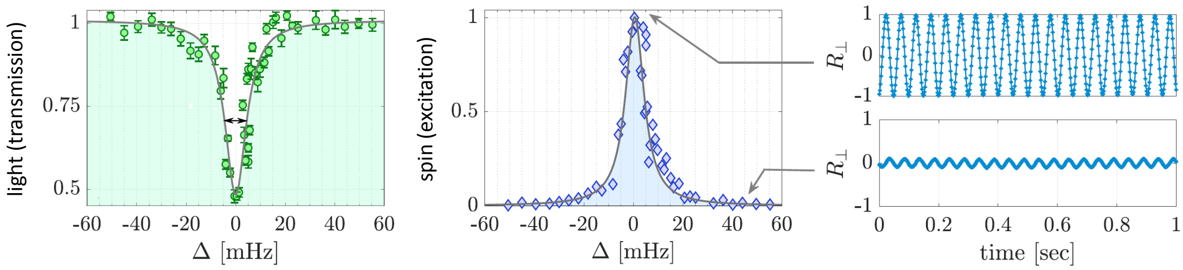

Figure 1. Optical spectroscopy and excitation of helium-3 spins. Left: Transmission of one quadrature of the signal light versus the signal frequency detuning Δ. The sharp spectral line, of width 10.5 ± 1.4 mHz (millihertz), is obtained due to a two-photon process, when the frequency difference between the signal and control fields approaches the nuclear magnetic resonance of the noble gas. Right: Optical excitation of noble-gas spin coherence. Insets show the measured precession signals on and off resonance.

[1] O. Katz, R. Shaham, O. Firstenberg, arXiv:**1905.12532** (2019).
[2] R. Shaham, O. Katz, O. Firstenberg, Phys. Rev. A **102**, 012822 (2020).
[3] O. Katz, E. Reches, R. Shaham, A. V. Gorshkov, O. Firstenberg, arXiv:**2007.08770** (2020).
[4] O. Katz, R. Shaham, E. Reches, A. V. Gorshkov, O. Firstenberg, arXiv:**2007.10177** (2020).
[5] R. Shaham, O. Katz, O. Firstenberg, arXiv:**2102.02797** (2020).
[6] O. Katz, R. Shaham, O. Firstenberg, arXiv:**2102.00229** (2021).
[7] O. Katz, R. Shaham, E. S. Polzik, O. Firstenberg, Phys. Rev. Lett. **124**, 043602 (2020).