Coupling between alkali & rare gases for vapor-based quantum memories

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Hot atomic vapors in optically pumped magnetometers (OPMs) are a perfect quantum system offering a wide field of applications. The spectrum ranges from magnetic field sensing, where gaseous atoms fulfill their role as highly magnetic sensitive probes, to applications in quantum information, where OPMs can be quantum memories. A common approach to establish such memories is to map the photonic state onto optically accessible matter states. A recent achievement uses ^{133}Cs as an optical interface for photons stored in collective spin excitation via EIT [1]. Such methods achieve storage times in the order of microseconds. One of the main challenges is to extend the storage time of such photonic states. Here, the nuclear spin of rare gases is qualified due to its 'shielded' nature by complete electron shells, allowing the preservation of the spin precession for several minutes or even hours [2].

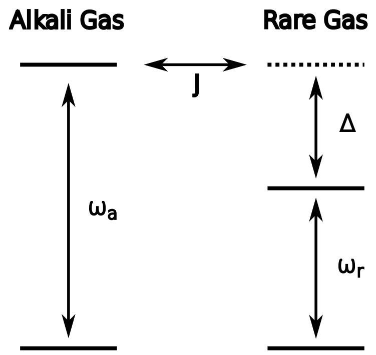

Figure 1. Two-level system of the Larmor precession frequencies for the alkali ω_a and rare gas ω_r coupled by J. Altering the external field Δ, which is a function of B_0, allows a strong coupling via spin-exchange collisions.

Unfortunately, rare gases lack convenient optical access, and addressing their nuclear spin becomes a challenge. To overcome this issue, one couples the electron spin of the alkali gas to the spin of the nuclei of the rare gas via spin-exchange collisions. Under ambient conditions, the transition of the polarization of the alkali atom to the rare gas happens within tens of thousands of collisions. The better the coupling J between those two scattering partners is, the more efficient the polarization transfer. It stands to reason that parameters given by the engineered system, such as the effective polarization p_a and p_r and the number density of the gases n_a and n_r are determinative parameters for $J \approx \sqrt{n_a n_r p_a p_r}$. However, those parameters are not the only possible channels for tuning the coupling strength. R. Shaham *et al.* [3] discussed a method for how to achieve strong coupling between the electron spin of potassium and the nuclear spin of helium via altering B_0 in a two-level frame (Fig. 1).

Our experiment follows the proposed scheme to achieve strong coupling between a hot ensemble of rubidium and helium atoms. Those are the first steps towards a most efficient quantum memory device and further fundamental studies of alkali and rare gas spin dynamics.

[1] L. Esguerra *et al.*, Phys. Rev. A (2023) 107, 042607
[2] C. Gemmel *et al.*, Eur. Phys. J. D (2010) 57, 303
[3] R. Shaham *et al.*, Nat. Phys. L (2022), Vol. 18, No. 5