Squeezing and Entanglement of Nuclear Spins by Localized Electron

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Quantum entanglement of a few particles has already been well studied, both theoretically and experimentally. In a series of works [1, 2, 3] we describe collective entanglement and squeezing of many (up to 10^6) nuclear spins in quantum dots through the hyperfine interaction with an optically driven electron spin.

We describe the spin dynamics in a singly charged quantum dot using a central spin model in the box approximation. In the limit of many nuclear spins, we find its exact analytical solution. It represents a superposition of the nuclear spin precessions around an external magnetic field in opposite directions with a common frequency that depends nonlinearly on the magnitude and direction of the total nuclear spin [1, 2]. Based on this result, we propose a protocol for generating squeezed nuclear spin distributions [see example in the inset in Fig. 1(a)]. The degree of the nuclear spin squeezing is shown in Fig. 1(a) as a function of time, and parameter $\xi_s < 1$ indicates entanglement between nuclear spins in the quantum dot. The stars highlight the instances, when the metrological spin squeezing is achieved. A modification of the protocol allows one to generate a maximally entangled spin state, which represents a coherent superposition of nuclear spin polarizations in the opposite directions (the GHZ state).

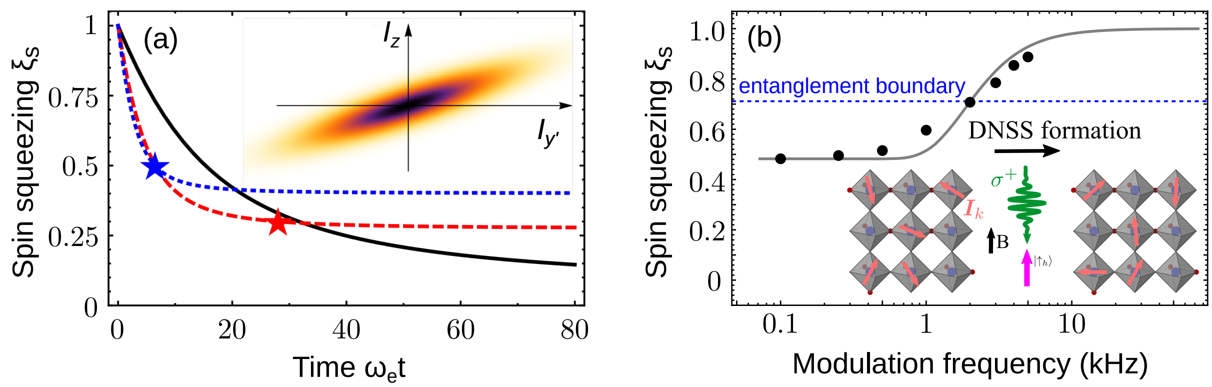

Fig. 1. (a) Evolution of the nuclear spin squeezing degree for initial polarizations of 10% (black), 30% (red), and 50% (blue). The inset shows an example of squeezed spin distribution. (b) Spin squeezing of lead nuclei in $FAPbBr_3$ as a function of the optical orientation modulation frequency. Dots and line show experimental results and theoretical model, respectively.

Nuclear spin squeezing and entanglement were experimentally realized in a bulk $FAPbBr_3$ perovskite crystal [3]. The spins of ^{207}Pb in this system can be manipulated through the hyperfine interaction with the spins of localized holes. Under optical orientation conditions with alternating helicity of the exciting light, squeezed dark nuclear spin states were generated. This was evidenced by measuring the hole spin polarization recovery curve in small longitudinal magnetic fields. The degree of nuclear spin squeezing is shown in Fig. 1(b) as a function of the helicity modulation frequency. The theoretical analysis indicates the presence of at least 35-body entanglement among 60 Pb spins.

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References

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