Vienaašio sukinių suspaudimo fermioninių atomų optinėse gardelėse modeliavimas

Simulation of one-axis squeezing with atomic fermions in optical lattices

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Enormous progress in developing strategies for surpassing classical limits on measurement precision in quantum metrology has been made [1]. A key element here is spin squeezing that is one of the most promising strategies for using entanglement to achieve a quantum advantage in practical high-precision sensing applications [2].

Estimation of the spin squeezing level is obtained as

$$\xi_s^2 = N\frac{\Delta^2 \hat{S}_{\perp\min}}{\langle S\rangle^2} \tag{1}$$

where $\langle S\rangle$ is the length of the mean collective spin and $\Delta^2\hat{S}_{\perp\min}$ is the minimal variance of the spin orthogonally to the mean spin direction i.e., spin squeezing is a quantum correlation with reduced fluctuations in one of the collective spin components.

Ultracold atomic Fermi gases in an optical lattice are used in the most precise and accurate optical lattice clocks (reaching precision record $\sim 3 \times 10^{-19}$ [3]), as the Pauli exclusion principle suppresses unwanted collisional frequency shifts. Furthermore, ultracold atomic gases in optical lattices are nearly perfect for realization of many condensed matter phenomena i.e., they offer various kind of Hubbard models with great flexibility of parameters [4] (Fig. 1).

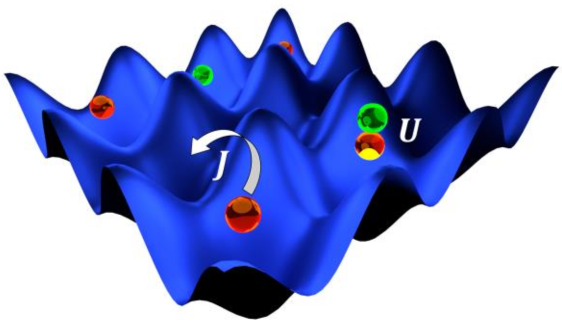

Fig. 1 A Fermi-Hubbard model with ultracold atoms trapped in the lowest band of an optical lattice. Due to Pauli's principle, tunnelling between lattice sites *J* is only possible if the final lattice site is empty or occupied with an atom with a different spin. Two atoms with opposite spin localized at the same lattice site have an interaction energy *U*. The *J/U* ratio and the filling determines the physics of the system.

Recently it was suggested that the interaction among identical atomic fermions needed for the spin squeezing can be induced via the spin-orbit coupling (SOC), which is generated by means of an additional laser that drives the clock transition [5].

In this work, we investigate spin-squeezed states in an optical lattice composed of ultra-cold fermions employing position-dependent SOC that can be induced in realistic experimental conditions. By choosing an appropriate propagation direction of the laser beam inducing the SOC and acting on a fermionic lattice with a sequence of such laser pulses we expect to realize efficient spin-squeezing. Additionally, we demonstrate that Hamiltonian suggested by K. Gietka [6]

$$\hat{H} = \hbar\chi\hat{J}_z^2 \tag{2}$$

can be efficiently simulated with SOC and thus create a spin squeezing. The presented method might find application in different areas of ultraprecise metrology, where the quantum improvement is of great importance.

Key words: quantum metrology, optical lattices, spin squeezing, Fermi-Hubbard model.

References

[1] L. Pezz`e, A. Smerzi, M. K. Oberthaler, R. Schmied, and P. Treutlein, Rev. Mod. Phys. **90**, 035005 (2018).
[2] M. A. Perlin, Ch. Qu, A. M. Rey, Phys. Rev. Let. **125**, 223401 (2020).
[3] G. E. Marti *et al*., Phys. Rev. Lett. **120**, 103201 (2018).
[4] F. Schafer et al., Nat. Rev. Phys. **2**, 411 (2020).
[5] P. He et al., Phys. Rev. Research **1**, 033075 (2019).
[6] K. Gietka et al., Phys. Rev. A **92**, 043622 (2015).