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# Abstract

This thesis focuses on theoretical schemes concerning the preparation and characterization of both squeezed and entangled quantum states in the spinor Bose-Einstein condensate with a total spin $F = 1$. The subject matter of the study covers two issues, discussed in the publications [1,2], and it also provides more insights into the topic. In the first part, we show that the equilibrium states of the spinor $F = 1$ Bose-Einstein condensate in the external magnetic field are highly entangled. This statement concerns both pure ground states and mixed by the temperature states (equilibrium in internal degrees of freedom), irrespectively of the system's magnetization, which is a population difference between extreme Zeeman states. Aforementioned conclusion is based on the analytical and numerical studies of the quantum Fisher Information, which quantifies not only the metrological usefulness of quantum states for quantum interferometry, but also their entanglement depth. Regardless of the system's parameters, the quantum Fisher Information has the Heisenberg scaling $\propto N^2$, where $N$ is the total number of atoms. This means that the equilibrium states of the spinor Bose-Einstein condensate can be used for entanglement-enhanced quantum interferometry with precision below the standard quantum limit. It applies both to the three-mode interferometry and its two-mode variant due to symmetry of obtained states. The second topic, based on numerical simulations, indicates that the long-range dipolar interactions in the spinor $F = 1$ Bose-Einstein condensate can be utilized for dynamical generation of strongly spin squeezed quantum states. The main assumption, in the theoretical description, is based on the separation of internal and external degrees of freedom. Due to presence of non-linear interactions, initial quantum state of independent atoms evolves in time generating a squeezed state. The scaling of the squeezing parameter, which quantifies the level of squeezing, with the total number of atoms is the same as in the one-axis twisting and two-axis countertwisting models proposed as theoretical protocols for dynamical generation of squeezed quantum states. In the examined system, the abstract scheme has a direct physical realization. The dominance of one model over another depends on the geometry of the external trapping potential.

1. Kajtoch, D., and Witkowska, E., Spin squeezing in dipolar spinor condensates, **Phys. Rev. A 93, 023627 (2016)**.

2. Kajtoch, D., Pawłowski, K., and Witkowska, E., Metrologically useful states of spin-1 Bose-Einstein condensates with macroscopic magnetization, **Phys. Rev. A 97, 023616 (2018)**.

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